McCarl contribution to ED Document
Terrestrial GHG Quantification and Accounting

1 Prices across a market

Different prices for consumers and producers are uniformly observed within any agricultural or forestry market. Furthermore, observed prices differ both

- between producers and consumers and
- between different lots of the commodity depending on variations in commodity quality.

Such price differences can be explained by systematic factors. The wedge between producer and consumer prices occurs because of the incidence of marketing costs (transport, handling etc.) incurred in conveying the commodity from producers to consumers.

Differential prices for lots of the same commodity at the same location are commonly caused by a market defined system of grades for the commodity. Such grades reflect differential use values on behalf of commodity consumers depending on commodity quality characteristics coupled with the production costs of achieving different commodity quality characteristics. For example, in plywood markets there are different prices for a sheet of plywood depending upon the quality of the surface finish (smoothness, freedom from knots etc) while in the corn market there are differential prices per bushel depending upon the moisture content, and the incidence of foreign matter/broken kernels in the bushel at hand. Grading standards are generally defined to reflect consumer preferences. In turn, the market price differentials that arise across commodity grades reflect the different prices that consumers are willing to pay for commodity units of different qualities.

It is virtually certain that grading standards will also occur in a GHG offset credits market. In a GHG market, the grading standards would reflect different characteristics that are important to the purchaser including:

- The extent to which the characteristics of the particular GHG offset at hand allows the purchaser to comply with the rules or regulations that define the GHG emission regulatory program.
- The amount of regulatory system certified offsets that can be gained by registering the offset at hand.

1.1 Differentiating characteristics

In the domestic and international policy discussion directed toward net GHG emission reductions a number of concepts have arisen that are likely to differentially characterize the contribution of alternative possible offsets within the total regulatory structure. These involve:

- Permanence

- Additionality
- Leakage
- Uncertainty
- Heat trapping ability of different gases involved (as commonly called global warming potential or GWP).

In all likelihood grading standards will differentiate based on the characteristics listed above between a certified offset price and the price for potential offsets from a number of sources. Likely sources of differentiated potential offsets are sequestration offsets, carbon dioxide emission offsets, nitrous oxide emission offsets and methane offsets. A brief overview of the listed characteristics is given immediately below with more extensive coverage in later chapters

1.1.1 Permanence

The total quantity of potentially creditable GHG offsets generated by land-based, particularly sequestration, projects cannot be guaranteed to be permanent because of potential reversal of the practices that generated the potential offsets and the incidence of potential uncontrollable events that would lead to release of the sequestered GHGs. Such a concern has come to be known as ***permanence*** in the discussion surrounding GHG offset markets, policy and rulemaking. The permanence concern embodies a number of different concepts including:

- The likelihood that some sequestered carbon might be emitted in the future (volatility).
- The fact that differential annual amounts of GHG activities generally arise over time.
- Leasing and contract terms.

The main permanence issues given a proposed project are

- What is the differential value of non permanent potential versus permanent fully creditable emissions offsets? and
- How do contract terms on project duration influence the creditable value of an offset?

1.1.2 Additionality

In the discussions international GHG regulatory discussion, policymakers have reflected a desire to only credit GHG offsets that would not have occurred under the normal course of business (commonly called business as usual). Similarly, credit buyers would naturally desire to pay only for GHG offsets that they can claim credit for under regulatory schemes. Thus, buyers would not wish to pay for potential offsets that someone would disallow. Within the GHG offset discussion such a concern has come to be called ***additionality***. The widely held stance arising is that the rulemaking and regulatory structure should only grant credits for GHG offsets that are additional to what would have occurred under business as usual.

The main additionality issues, given a proposed project, are

- How much of the potential GHG offsets created by a project would have occurred in the absence of the program? and
- How much should the potential offsets created by the project be reduced to account for the activity that would have occurred in the absence of the program? Or equivalently How much should the potential offsets de discounted to account for the non additional portion so they are creditable offsets?

1.1.3 Leakage

Market forces coupled with less than global coverage by a GHG regulatory program can cause net GHG emission reductions within one region to be offset by increased emissions in other regions. For example, suppose land management within a region is altered in the name of a GHG offset program resulting in increased sequestration, less emissions and less land based production, but suppose, in turn, that there are land management reactions in other regions replacing the lost production leading to increased emissions in those regions. This implies that the global net emission reduction is less than would be implied by just looking at the project. Such a phenomenon has been called ***leakage*** in the context of GHG rulemaking.

In terms of a more concrete example, suppose that a GHG program caused a significant realignment in U.S. land use with crop production being reduced and forest land increased. In turn due to reduced crop production crop prices would rise. Simultaneously a larger forest inventory would cause future expectations for forest product prices to fall. Now suppose that this price realignment stimulates increased crop and reduced forest production internationally coupled with increased tropical deforestation (to get the crop land). Such an action would increase emissions in the tropical areas partially or fully negating any global gains in GHGs that occurred directly within the US offset program.

The main leakage issues given a proposed project are

- How much leakage does a GHG project stimulate? and
- How much should the potential offsets created by the project be reduced to account for the leakage stimulated? Or equivalently How much should the potential project created assets be reduced to account for the leakage so they are creditable offsets?

1.1.4 Uncertainty

Land-use based production of GHG offsets will be subject to production and sampling uncertainty. Production uncertainty arises in much the same fashion as it does for any other agricultural or forestry commodity. Year-to-year weather variations along with the uncertain incidence of fire, diseases and pests coupled with many other factors will cause this uncertainty. Yields of crops commonly vary by 10% or more of their average value.

Uncertainty also arises due to sampling issues. Measurement of GHGs across the landscape is not possible. Sequestered GHG concentrations and emission reductions are widely spread across every square inch of the landscape. From a practical viewpoint one can never measure such geographically dispersed offsets. One must rely on sampling and with sampling comes error causing uncertainty.

Collectively the natural production and sampling uncertainty will exist and thus the purchaser of potential GHG offsets will be at risk of having the quantity of purchased offsets falling below the claimed level of offsets causing the purchaser to be out of compliance with regulatory limits. This coupled with potential compliance penalties leads to the ***uncertainty*** concern that has arisen in the consideration of GHG markets.

The main uncertainty issues given a proposed project are

- What is the magnitude of the uncertainty?
- Will uncertainty based discounts arise that reflect the potential liability that a buyer would incur if found to have a net emissions in excess of mandated emission limits?
- Can the uncertainty be reduced?
- How much should the potential offsets created by the project be reduced to account for the uncertainty about the total volume generated? Or equivalently How much should the potential project created assets be reduced to account for the uncertainty so they are creditable offsets?

1.1.5 The GWP concept

Different gases have different effects when released into the atmosphere in terms of their potential for trapping solar radiation and contributing to the overall global warming problem. Land-based projects principally involve changes in the net emissions profile of three gases

carbon dioxide
nitrous oxide
methane.

Since differential compositions of these three gasses occur across projects in terms of relative contribution to total project net offsets, it is desirable to normalize their emissions by establishing a relative measure of their contribution to the global warming problem. Several different approaches have been taken to establish numerical measures of relative contributions. The most common approach is commonly referred to as the ***global warming potential*** or ***GWP*** (IPCC *Third Assessment Report - Climate Change 2001: The Scientific Basis).*

The GWP is a relative measure of the global warming contribution of a gas that is expressed in the form of a multiplier. In particular, scientists have developed multiplicative factors that express the relative amount of solar radiation trapped by the release of a unit of gas into the atmosphere during a fixed time period. THE GWP multiplier is developed relative to carbon dioxide with it given a multiplier of one and nitrous oxide given a value of K indicating that one ton of nitrous oxide creates K times as much warming as a ton of carbon dioxide. The GWP concept is also developed relative to a time period indicating the amount of warming created over a given duration. The common hundred year GWP multiplier rates a ton of carbon dioxide use at 1 while a ton of methane is rated with a GWP of 21 and a ton of nitrous oxide at 310. This indicates the relative global warming consequence of releasing one ton of nitrous oxide is the same as the consequence of releasing 310 tons of carbon dioxide.

In a grading standard arena one would expect that the price of a ton of avoided nitrous oxide emissions would be 310 times that of a ton of avoided carbon dioxide emissions. A number of other measures of GWP have been developed including ones that are time dependent and that reflect the economic damages caused by release of gasses (see Manne and Richels or Reilly, Babiker, and Mayer for example).

Common practice reduces the collective quantity of all three emitted gases to either a carbon or a carbon dioxide equivalent basis. When reducing to a carbon dioxide equivalent basis, one sums the net emission offsets arising in terms of each gas times the global warming potential for the gas as in the following formula.

$$\mathrm{CO2EQ} = \sum_{gas} QGAS_{\mathrm{gas}} * \mathrm{GWP}_{\mathrm{gas}}$$

where

CO2EQ is the number of carbon dioxide equivalent units (usually metric tons) generated by the multi-gas portfolio of offsets anticipated under implementation of the project generally in metric tons.
$\mathrm{QGAS}_{\mathrm{gas}}$ is the estimated quantity of each particular gas that would be offset simultaneously by the project generally in metric tons.
$\mathrm{GWP}_{\mathrm{gas}}$ is the global warming potential normalization factor for each particular gas which is commonly 1 for carbon dioxide, 21 for methane and 310 for nitrous

If the conversion is being done to a carbon equivalent basis, then the above equation is in turn divided by ratio of the molecular weight of carbon dioxide to the molecular weight of carbon which is 3.667.

$$\mathrm{CEQ} = \frac{\sum_{gas} QGAS_{\mathrm{gas}} * \mathrm{GWP}_{\mathrm{gas}}}{3.667}$$

where in addition to the terms defined above

CEQ is the total number of carbon equivalent units arising from the offset reduction generated by the project

3.667 is the molecular weight of a unit of the compound carbon dioxide relative to the molecular weight of the carbon contained in the compound.

1.2 Category separation

It is important within the GHG project accounting context to separate potential offsets into differential categories to facilitate project evaluation and application of any relevant discounts. This separation is suggested for three reasons

- Not all potential offsets have the same characteristics in terms of uncertainty, additionality, leakage, permanence and GWP. Separation allows one to potentially apply different grading standard induced discounts or premiums relevant to the different offset categories to compute creditable offsets reflecting potentially different compliance characteristics in terms of GHG program emission regulations.
- Some potential offset categories are disallowed by the rules defining some GHG offset regulatory systems. For example, current Kyoto Accord related rulemaking disallows the generation of offsets from management of existing forests, immediate reforestation of harvested forest stands, avoided deforestation, and sequestration in harvested wood products.
- There are issues in terms of what can be claimed underneath a project. For example, under an offset credit system, it is unlikely that a landowner would be entitled to receive payment for the reduction in energy used in inputs not consumed. In the extreme case, if a power plant is buying an offset from the landowner and if the landowner uses less fertilizer and the fertilizer manufacture would use less electricity since they did not have to make the displaced inputs, then the credits for the reduced coal used in electricity generation may already enter into the power plant account and crediting them to the farmer would double count. However it may be important to consider this in the economic analysis as when the power plant faces GHG emission limits they are likely to pass the compliance costs on to electricity purchasers in the form of increased electricity prices.

In particular, it is recommended that one separate reported sequestration into

- Sequestration from changing agricultural land management,
- Sequestration from afforestation
- Sequestration from management of existing forests
- Sequestration from reforestation
- Sequestration from avoided deforestation
- Sequestration from harvested wood products
- Sequestration from conversion to grasslands

and other relevant categories.

Similarly, we recommend separation of emission offsets emission reductions by GHG (carbon dioxide, methane, nitrous oxide) and within each gas separating out

- ❖ Emission reductions from diminished use of fossil fuels,
- ❖ Reduced offsite emissions embodied in the creation of inputs that would have been used by the project under business of usual but are not being used now
- ❖ Direct emission reductions caused by altered land-use activities such as captured methane emissions from improvement in manure management practices, reduced nitrous oxide emissions from altered fertilization, etc.

and other relevant categories.

1.3 Price relationships between market actors

When considering offset discounts it is worthwhile considering how prices are transmitted between market actors. Namely, given a market price let us examine how this transmits down to the level of a project. Suppose that the potential offset at hand is subject to a set of discount factors before it becomes a creditable offset and that these discounts arise from the grading standards. Also suppose that in the process of a sale that there are some transactions costs incurred that are expressed on a per unit basis and that it is possible that a per unit government subsidy may be involved.

In such a case the relationship between the prices is as follows:

ProducerPrice = MarketPrice*(1-DiscountFactor) - TransactionsCost <u>+ Govt Subsidy</u>

This shows that the price a producer would receive for an offset is the market price adjusted

- ❖ Downward for the offset characteristics induced discount factors.
- ❖ Downward for the per unit transactions costs.
- ❖ Upward for the per unit magnitude of any government subsidies.

Thus, the producer price is likely to be smaller than the consumer price.

Similarly, suppose one wants to examine whether a potential offset created by a project will be price competitive in a market with an established price. In that case, one would add up the per unit offset price that needed to be paid to producers plus any per unit transactions costs less any per unit government subsidies and then divide by the appropriate discount factor as follows.

(ProducerCost + TransactionsCost - Govt Subsidy) /DiscountFactor

For the offset to be competitive the result of this calculation needs to be less than or equal to the current market price.

1.4 Deriving a discount factor

Rules governing the ways that potential GHG offset credits can converted to claimable offsets are likely to include considerations reducing the potential offset quantity to a quantity that can be claimed in the face of leakage and additionality. In addition, such rules will in all likelihood require that the potential offsets claimed be in fact produced with an acceptable degree of certainty along with a noncompliance penalty when shortfalls are attained. This involves uncertainty issues. Finally, there a program will require credits to be held for some specified length of time which raises permanence issues. In turn, purchasers acquiring credits are likely to be concerned about additionality, leakage, permanence and uncertainty and will be likely to pass on a discount that reflects the consistency of the potential offsets with the purchasers' ability to claim offsets in compliance with the GHG program rules.

Not all potential offsets will have the same characteristics in terms of uncertainty, additionality, leakage, and permanence. In this regard, suppose one is comparing two offset possibilities. Suppose one of these generates offsets that are totally additional, that exhibit zero leakage, that are totally permanent and that exhibit no uncertainty. However, suppose the other does not have such idealized characteristics. In this setting then there is the likelihood that a discount will arise. Now suppose we develop a general conceptual approach to discount establishment. First, however, we need some background on time value of money, offsets and a current equivalent cost.

1.4.1 Concepts involved in offset discount calculation

Offsets from a project may have different characteristics as they arise over time. Thus, it is worthwhile discussing key concepts required to the value the time dependent assets. The basic concepts constitute a way of bringing future payments and offset quantities back to the current time. Concepts that will be discussed are the present value of future payments, the present value of future offsets and the per unit present value of an offset.

1.4.1.1 Value of a time dependent asset

The basic concept employed to derive the current and future value of a time varying expenditure and income stream is called the time value of money or net present value formulation. The motivating concept is that if one is given a dollar today and puts it in the bank, then a year from now one would have that dollar times one plus the interest earned as shown in the following formula.

$$\begin{aligned} MoneyNextYear &= MoneyToday + Interest * MoneyToday \\ &= (1 + Interest) * MoneyToday \end{aligned}$$

Thus, if one is given \$100 today and puts it in the bank at 5% interest, then after a year the available funds would be \$105. Equivalently, one can look at the present value of the receipt of money tomorrow in terms of the equivalent value of money on hand today by dividing besides the equation through by one plus the interest-rate which is commonly called the discount rate (Disc).

$$\text{MoneyToday} = \text{MoneyNextYear} / (1+\text{Interest})$$

So the value of $105 received a year from now in an economy with a 5% interest rate is $100 today.

More generally, when expenditures and income streams arise over time, then the present value of the streams can be derived by dividing the increment in year N by one plus interest rate raised to the Nth power as in the formula below

$$\text{MoneyToday} = \text{MoneyInYear}_N / (1+\text{Interest})^N$$

Furthermore, when money arises over a number of different years as denoted by MoneyInYear_i the general time value of money or discounting formula to bring this to a current basis is as follows:

$$\text{MoneyToday} = \sum_{t=0}^{T} \frac{\text{MoneyInYear}_i}{(1+\text{D}isc)^t}$$

where T is the total length of the time period being considered and Disc is the interest rate.

In this framework the interest-rate is commonly called the discount rate and is established as discussed in the next section.

1.4.1.2 Establishment of the discount rate

The discount or interest rate is generally an inflation free measure of the real value of returns to invested capital and is the interest-rate observed in the economy adjusted downward to eliminate the effects of inflation. There is a lot of literature on the establishment of an interest rate which yields complex calculation procedures. Simplistically, the discount rate can be viewed as the nominal interest-rate observed in the economy minus the inflation rate. Thus, if we have 5% interest and a 1% rate of inflation we would be using a 4% real interest-rate. In general, we recommend usage of a 4% rate.

1.4.2 Cost pet unit offset

Now suppose we develop a formula for cost per unit offset. To do this we develop a formula for total current cost, then total current quantity offset and then current cost per current unit offset.

1.4.2.1 Current cost of a GHG offset

GHG offsets developed by land related projects in general cost different amounts and yield differing quantities of offsets over time. Thus, there is the need for a measure of the current equivalent cost of purchasing the GHG offset when comparing two projects. Such a measure can be developed using the net present value concept.

$$\text{PresentValueCostOfOffset} = \sum_{t=0}^{T} \frac{\text{PriceOffsetInYear}_t\ \text{QuantityOffsetInYear}_t + OtherCost_t}{(1+\text{D}isc)^t}$$

Where

PriceOffsetInYear$_t$ is the price paid under the contract per unit of the offset in year t

QuantityOffsetInYear$_t$ is the quantity of offset created by the project in year t

OtherCost$_t$ is the amount of other costs paid under the contract that are not a function of how much offset is created under the contract for project in year t (such as an initial lump sum or ongoing maintenance costs).

This formula incorporates non-constant GHG offset prices within the offset contract. Such non-constant prices might occur if we observe:

- Increasing marginal damages accumulating over time as atmospheric concentrations increase.
- Falling offset prices as new technologies are developed which permit less emission intensive or emission free energy generation methods.

and the contract is indexed according to the market price.

Under such circumstances, if we define the price in year t as PriceOffsetInYear$_t$ which equals a contract price escalation factor CP_t times the base price P_0.

$$\text{PriceOffsetInYear}_t = CP_t * P_0$$

In such a circumstance the formula for the equivalent cost paid for the offsets in todays currency becomes

$$\text{PresentValueCostOfOffset} = \sum_{t=0}^{T} \frac{P_0\, CP_t\ \text{QuantityOffsetInYear}_t + OtherCost_t}{(1+\text{D}isc)^t}$$

1.4.2.2 Current offset equivalent of a GHG offset

GHG offsets developed by land related projects in general arise in differing quantities over time. Thus, there is the need for a measure of the current equivalent amount of GHG offsets when comparing two projects. Such a concept has been developed in the literature (Richards, 1997). The concept is based on the present value of a ton of offset produced in year t

$$\text{PresentValueOffsetInYearN} = \text{PriceOffset}*\text{QuantityOffsetInYear}_{N/}\ (1+\text{Disc})^N$$

However, this is denominated in dollars. If we wish to get the value of the average GHG offset increment we can divide the equation through by the carbon price

$$\text{QuantityOffsetToday} = \text{PresentValueOffsetInYear}_{N}/\ \text{PriceOffset}$$
$$= \text{QuantityOffsetInYear}_{N}/\ (1+\text{Disc})^{N}$$

Thus, the equivalent value of offsets that arise over time in terms of an equivalent quantity of offsets realized today is typically calculated as

$$\text{QuantityOffsetToday} = \sum_{t=0}^{T} \frac{\text{QuantityOffsetInYear}_t}{(1+\text{Disc})^t}$$

This formula can also be generalized to incorporate non-constant GHG offset prices. As above such non-constant prices might occur if we observe

- Increasing marginal damages accumulating over time as atmospheric concentrations increase.
- Falling offset prices as new technologies are developed which permit less emission intensive or emission free energy generation methods.

Under such circumstances, if we define the price in year t as P_t which equals a price escalation factor EP_t times a constant the base price P_0.

$$P_t = EP_t * P_0$$

Note, this does not have to equal the price escalation in the contract which is why we use CP above and EP here.

In such a circumstance, the formula for the equivalent quantity of offsets today becomes

$$\text{QuantityOffsetToday} = \sum_{t=0}^{T} \frac{EP_t * \text{QuantityOffsetInYear}_t}{(1+\text{Disc})^t}$$

1.4.2.3 Per unit value of an offset

Now let us establish a formula for the present value the purchaser pays for an offset per ton of currently equivalent quantity of offset. This can be expressed under constant offset prices by the following formula

$$\text{CurentCostPerOffsetTon} = \frac{\sum_{t=0}^{T} (OffsetPrice * QuanOffset_t + OtherCost_t)/(1+Disc)^t}{\sum_{t=0}^{T} ClaimQuanOffset_t/(1+Disc)^t}$$

where

OffsetPrice is the price paid for the offset which is assumed to be constant over time,

$ClaimQuantOffset_t$ is the quantity of offset obtained from the project that can be claimed as being in compliance with the GHG program in year t,
$OtherCost_t$ is the other non offset quantity related costs paid by the purchaser in year t that are above and beyond the price paid for any offsets,
Disc is the discount rate, and
T is the total time period being considered.

In this formula, the numerator is the net present value of the money spent in total for all offsets purchased plus any other costs paid during the total life of the project. The denominator is the net present value of the quantity of claimable offsets developed during a project life. The division of these terms yields a result equivalent to the division of total cost by the total quantity of claimable offset obtained. Such a division yields an average net present value cost per ton of offset obtained.

If one generalizes this formula to include escalation in offset and contract prices over time, the consequent formula becomes

$$\text{CurentCostPerOffsetTon} = \frac{\sum_{t=0}^{T} (OffsetPrice_0 * CP_t * QuanOffset_t + OtherCost_t)/(1+Disc)^t}{\sum_{t=0}^{T} (EP_t * ClaimQuanOffset_t)/(1+Disc)^t}$$

where

$OffsetPrice_0$ is the base period offset price.
CP_t is the relative proportion of the base offset price that is paid to the offset producer under the contract in year t.
EP_t is the relative proportion of the base offset price that the market price is in year t.

1.5 Establishing discounts

Finally, we arrive at a point where we can unify the material above and develop an expression for a discount. Suppose an offset purchaser is buying a new offset and already owns others and wants to pay the same amount for the new one as for the old one. Furthermore assume the new prospects has less than perfect permanence, additionality, leakage or uncertainty characteristics while the existing one is perfectly permanent, totally additional, stimulating no leakage without any uncertainty (for example an offset involving the destruction of a metered amount of methane from a hog operation that involves an investment never seen before that would not have arisen otherwise).

Now how would a discount arise? Let us assume the purchaser would be willing to pay the same price per ton for each prospect.

$$\text{CurrentCostPerOffsetTon}_{perfect} = \text{CurrentCostPerOffsetTon}_{other}$$

But, in offering the price for the offset that is not perfect suppose a price discount is applied as follows:

$\text{CurrentCostPerOffsetTon}_{other}$ =

$$\frac{\sum_{t=0}^{T} (Offset\,Price_0 * CP_t * (1 - PrDiscount) * PotentialQuanOffset_t + OtherCost_t) / (1+Disc)^t}{\sum_{t=0}^{T} (EP_t * ClaimQuanOffset_t) / (1+Disc)^t}$$

while no discount is paid on the perfect item. In turn, we can derive the value of the discount.

For simplicity, let us first develop a discount in the absence of offset price and contract price escalations ie (CP_t=EP_t =1). Also let us assume the perfect prospect involves

- Other cost levels equaling zero ($Othercost_t$=0)
- A constant amount of offsets generated in each and every year ($PotentialQuanOffset_t$=PotentialQuanOffset and $ClaimQuanOffset_t$=ClaimQuanOffset).
- 100% claimable offsets (PotentialQuanOffset=ClaimQuanOffset=QuanOffset).

In turn, after substitution, the cost per ton of the perfect prospect is

$$\text{CurrentCostPerOffsetTon}_{emission} = \frac{\sum_{t=0}^{T} (Offset\,Price_0 * QuanOffset + 0) / (1+Disc)^t}{\sum_{t=0}^{T} QuanOffset / (1+Disc)^t}$$

which since the price and quantity terms are not subscripted with a t can be simplified to become

$$\text{CurrentCostPerOffsetTon}_{emission} = \frac{Offset\,Price_0 * QuanOffset * \sum_{t=0}^{T} 1/(1+Disc)^t}{QuanOffset * \sum_{t=0}^{T} 1/(1+Disc)^t}$$

After removing common terms from the numerator and denominator this equation simplifies to just the price of the offset.

$$\text{CurrentCostPerOffsetTon}_{emission} = \text{OffsetPrice}_0$$

On the other hand, with contract and offset prices changing we get

$$\text{CurentCostPerOffsetTon}_{perfect} = Offset\,Price_0 * \frac{\sum_{t=0}^{T} CP_t / (1+Disc)^t}{\sum_{t=0}^{T} EP_t / (1+Disc)^t}$$

If in turn, we return to our formula where we equate the costs per unit

$$\text{CurrentCostPerOffsetTon}_{perfect} = \text{CurrentCostPerOffsetTon}_{other}$$

Then we get

$$\text{OffsetPrice}_0 = \frac{\sum_{t=0}^{T} (Offset\,\mathrm{Pr}\,ice_0 * (1 - \mathrm{Pr}\,Discount) * QuanOffset_t + OtherCost_t\,) / (1 + Disc)^t}{\sum_{t=0}^{T}\ ClaimQuanOffset_t \,/\, (1 + Disc)^t}$$

or

$$Offset\,\mathrm{Pr}\,ice_0 * \frac{\sum_{t=0}^{T} CP_t \,/\, (1 + Disc)^t}{\sum_{t=0}^{T} EP_t \ \,/\, (1 + Disc)^t} = \frac{\sum_{t=0}^{T} (Offset\,\mathrm{Pr}\,ice_0 * CP_t * (1 - \mathrm{Pr}\,Discount) * QuanOffset_t + OtherCost_t\,) / (1 + Disc)^t}{\sum_{t=0}^{T} (EP_t * ClaimQuanOffset_t) / (1 + Disc)^t}$$

and this can be solved for the price discount. This will not be done yet but will be reserved for the cases below where particular features will be introduced regarding permanence, additionality, leakage and uncertainty.

2 Permanence

The issue of permanence has been widely discussed in the debate over potential GHG abatement policy particularly in the context of carbon sequestration/sinks possibilities (See IPCC, 2001 for discussion and references). As discussed, the permanence concept encompasses a number of dynamic topics. Fundamentally these are the:

- Possibility that an increment of sequestered carbon will remain sequestered over the long term.
- Potential differential rate of offset accumulation over time.
- Approach to sequestration equilibrium by an ecosystem which leads to differential rates of accumulation over time and a long run decline to near zero.
- Contract terms and possible maintenance costs involved in the project payment scheme.

The discussion below ranges across all of these topics. We first will present some key permanence related features and then later apply the above discount derivation framework.

2.1 Key permanence related features

2.1.1 Volatility of sequestered carbon

GHGs can be sequestered biologically in ecosystems. The GHGs sequestered are largely in the form of carbon although some recent results also show that soils can sequester methane. Throughout the rest of this chapter, we will only address the carbon sequestration issue.

Sequestered carbon is generally retained either in the soil or the standing vegetation (note only standing vegetation that remains for more than one year should be considered). Soil carbon sequestration is enhanced by altering soil management practices or land use so that relative to the previously used practice/land use the rate of carbon input to the soil/ecosystem is increased or the rate of carbon decomposition is decreased. This is generally done by increasing vegetative cover, or reducing soil disturbance although many other strategies are possible (see Lal et al for elaboration). Once carbon is sequestered within the soil, the possibility exists that practices could be altered which decrease carbon inputs or increase decomposition either of which would decrease sequestration. For example, if carbon was sequestered by reducing tillage intensity then if in the future tillage intensity were increased this would lead to a release of sequestered carbon. The permanence issue in this case is: To what extent can one rely upon the assumption that in the future the sequestering practices will not be discontinued.

Similarly, when carbon is sequestered in standing vegetation like trees then the carbon is physically stored in the bole, limbs, vegetation and roots (for example the weight of wood in trees is approximately 50% made up of carbon). Such vegetative based storage is not necessarily permanent. Decisions or events that cause the death of the standing trees lead to decomposition of the wood and carbon release back to the atmosphere. Forest harvest is an example, although the extent of carbon release depends on the longevity of the use to which the derivative wood products (about 50% of total volume) are placed. In addition, the incidence of fire and pest infestations are examples of events that could occur which would lead to carbon releases.

The volatility part of the permanence issue is embodied in the question: To what extent can a purchaser rely upon the sequestered carbon to remain sequestered for the long-term? Equivalently the question can be expressed as: To what extent is the purchaser at risk that the carbon will be released by either altered management decisions or stochastic events?

2.1.2 Dynamic stream of sequestered carbon accumulation

An important issue in the sequestered carbon, permanence context involves the expected rate of accumulation of sequestered carbon over time. In this regard, a key concept involves the rate of accumulation and its approach to a new equilibrium under a particular management system.

The amount of sequestered carbon in an ecosystem will reach equilibrium when the rate of carbon inputs to the ecosystem equal the rate of carbon outputs from the ecosystem. When a carbon sequestration enhancing practice is adopted, initially the rate of carbon inputs to the ecosystem exceeds the amount decomposing. However, as carbon accumulates the amount of carbon decomposing increases and eventually the carbon input and output come into equilibrium. When this occurs, then the carbon is in equilibrium and the observed carbon accumulation will cease.

The approach to equilibrium has been commonly called saturation in the literature where the carbon accumulation only continues up until equilibrium under that practice is attained. At that point the soil carbon holding capacity in effect exhibits saturation under the utilized practice. However this saturation occurs under a particular practice and one can by adopting some other practice again increase carbon inputs relative to decomposition and again observe accumulation until the ecosystem attains a yet higher equilibrium. The key points are that that when following any particular strategy one will reach a point at which the rate of accumulation drops and eventually ceases.

Generally, sequestration measurements show an initial buildup followed by gradual reduction in accumulation until equilibrium is reached at which point the accumulation rate basically is zero. This is portrayed in the results of West et al that are shown in figure 1 where carbon accumulates up until a point at which equilibrium is reached "saturating" the capacity of the soil to sequester in its current use. West et al use the term duration to identify the time period up until which the rate of carbon accumulation stops. Birdsey's results show the same phenomena for forestry cases. This means the dynamic pattern of sequestration varies.

Another important carbon sequestration dynamics and permanence fact is the volatility of sequestered carbon. Namely if a new practice is adopted which diminishes the rate of carbon input relative to the rate of carbon decomposition then the carbon accumulation will be reduced and the volume of sequestered carbon will in fact fall back to a lower equilibrium state. Some people of have argued in the context of sequestered soil carbon this happens in as few as three years.

The final concept worth noting under the carbon dynamics topic is how long one should expect carbon accumulation to continue over time. West et al's agricultural data and Birdsey's forestry data indicates that the carbon accumulation rate under a given practice across

- Changes in tillage practices reach a new equilibrium within 20 years and West and Post assert this basically happens within 10-15 years for most projects.
- Changes in the way cropland is managed in terms of altered use of inputs like fertilizer or changed rotations showed that nonzero accumulation rates occur up to 40 years (West and Post)
- Afforestation or altered forest management in the southeastern United States show rates of accumulation continue for 80 plus years (Birdsey). Longer times to saturation occur in other types of forests (100's of years in some types- Brown et al).

2.1.3 Practice sustainability and maintenance costs

One issue as regards carbon sequestration involves practice sustainability and possible need for maintenance costs. Let us consider two cases

- An agricultural practice involving changes in tillage
- An afforestation project involving establishment of new forest on agricultural lands.

In terms of the agricultural tillage project, the basic sequestration action involves conversion for a more to a less intensive form of tillage such as switching from conventional tillage to reduced or no-till. Such an action would increase carbon sequestered but only up until the soil ecosystem reached a new equilibrium. The question then is: Once the rate of carbon sequestration falls to zero and carbon payments stop, is it profitable to continue the practice.

While a substantial amount of land in the United States is in reduced tillage practices, only a very small proportion of that land is continuously managed with nothing but reduced tillage practices. This implies that in the long run it may not always be viable to maintain continuous conservation tillage (although many agronomists argue this is a superior practice).

A key factor in possible suspension of reduced tillage is whether or not chemical weed control continues to be effective. Today there is emerging evidence that weeds could become resistant to certain herbicides that are now key to reduced tillage programs. Producer groups argue that the agricultural producer takes on risk when agreeing to long-term reduced tillage commitments (Bennett).

This introduces the potential need for maintenance payments as part of an offset contract to maintain a practice beyond the period of carbon accumulation. Property rights and liability for shortfalls are other key elements of this issue as will be discussed below.

The afforestation practice also involves sustainability issues. Once a stand of planted trees becomes mature, it is tempting to harvest them for wood products. Upon harvest a substantial amount of the sequestered carbon will be lost as generally 50% of the tree volume is immediately lost while harvest disturbance releases some of the associated soil carbon. In addition, upon harvest, land use could be altered into agriculture or urban usages either of which could substantially reduce carbon sequestration. Furthermore if the contract required that the trees not be harvested then the forest would be a long-term diversion of land from product based earnings and would need either maintenance costs or some vehicle for earning money based on recreational or amenity value.

The basic point is that maintenance costs may be needed to retain the sequestered carbon after the rate of accumulation falls or ceases.

2.1.4 Contract duration and liability schemes

Another key concept in the arena of carbon sequestration involves how contract duration and liability are established. There are two traditional systems that have been widely discussed

- ❖ Pay-as-you-go
- ❖ Leasing

2.1.4.1 Pay as you go

Under a pay-as-you-go system (as discussed in Watson et al., 2000, Feng et al (2001), Zhao et al(2002)) offset creators get paid and emitters must acquire offsets on a year by year basis. Thus, if a landowner creates offsets for a period of time they would be paid during that time. However, if they altered practices and stimulated releases during the period where they had contracted to maintain offsets then they would have to acquire permits for those releases. This will likely be a disincentive for the adoption of practices that may be subject to reversal. Further, if one anticipates future increasing carbon prices, then the future cost of replacing credits may be a substantial risk factor.

2.1.4.2 Contracts for limited time - leasing

An alternative and widely proposed contracting scheme for handling sequestration based offsets involves limited term leasing which has been proposed in various forms

- ❖ Expiring, or temporary certified emission reductions (see the “Colombian” proposal, 2000; Blanco and Forner, 2000; and Chomitz, 2000);
- ❖ Carbon “rental” (see Marland et al., 2001, Sedjo and Marland, 2003); and
- ❖ Carbon “leasing” (see Moura Costa, 1996; Dutschke(2001,2002), Dutschke and Schmalinger(2003).

Such practices involve a purchaser agreeing with a landowner that a sequestration practice would be employed for a given number of years. Then the contract would end and the purchaser would have to acquire offsets credits from elsewhere equal to the cumulative amount of offsets claimed during life of the contract. In turn, the landowner could

- ❖ Resell the volume of credits on hand at contract end taking on another lease.
- ❖ Change practices reverting back to a lower equilibrium without liability as long they did not fall below their initial baseline.

Such a practice places liability on the purchaser and would lead to a price discount based on permanence characteristics. This would also alter the price risk faced by both purchasers and sellers. Under such contracts purchasers would be able to take advantage of declining carbon prices but would be hurt by increasing prices. On the other hand landowners would not fully receive increasing carbon prices.

2.1.4.3 Annuity based contracts

Yet another contract basis would involve establishment of a payment schedule based on a long-run average amount of carbon accumulation rather than ton-year payments on the exact amount of offset generated in each year. Such an approach would reduce income and payment variation on behalf of both buyer and seller. This would likely be attractive as compared to pay as you go for afforestation possibilities where harvest is involved. Therein the offset level rises until harvest then falls but on reforestation begins to rise again. Payment on an annuity basis would even out income and expenditure flows. A discount below the average would probably also be present to account for purchaser needs for bridging credits upon harvest.

2.2 Discounts for permanence considerations

Given the above concepts we may now derive a formula for a grading standard motivated price discount for nonpermanent potential offsets. This will be done using the approach outlined in the previous chapter where the offset purchaser equates the cost per ton of offsets developed under a perfect offset with those from a project that has imperfect permanence characteristics.

To do this we develop an expression for the cost per ton incorporating a potential permanence discount. Then we equate the cost of the perfect offset with the cost of the potential imperfect offset and solve for the permanence discount.

2.2.1 Cost of a sequestration offset

Now suppose express cost per unit formula in the impermanent case. Here we take the formula above and assume that the price paid is one minus the permanence discount times the price that would be paid for the above emissions case. We also recognize that the quantity of potential offsets vary from year to year as does the possible incidence of maintenance costs and we include the need for the purchaser to buy credits (called buyback below) caused by the lapse of the contract or to offset the periodic release of sequestered carbon due to factors such as forest harvest. Thus, the cost per ton formula under constant offset prices becomes

$CurrentCostPerOffsetTon_{Sequest}$ =

$$\frac{\sum_{t=0}^{T}((1-PermDisc)*OffsetPrice_0*QuanOffset_t+OffsetPrice_0*BuyBack_t+MainCost_t)/(1+Disc)^t}{\sum_{t=0}^{T}(QuanOffset_t)/(1+Disc)^t}$$

where

$QuanOffset_t$ is the quantity of offsets generated by the project in year t that is paid for by the buyer, all of which are claimable.

$BuyBack_t$ is the quantity of offsets that need to be bought in the market place in year t due to expiration of the lease or other factors

$MainCost_t$ is the maintenance cost paid in year t that is independent of the quantity of offsets sequestered.

and under time differing offset prices and contract terms

$CurrentCostPerOffsetTon_{Sequest}$ =

$$\frac{\sum_{t=0}^{T}((1-PermDisc)*OffsetPrice_0*CP_t*QuanOffset_t+OffsetPrice_0*EP_t*BuyBack_t+MainCost_t)/(1+Disc)^t}{\sum_{t=0}^{T}(EP_t*QuanOffset_t)/(1+Disc)^t}$$

Now let us we solve the equations above for the permanence related price discount that equates the purchase price per ton between this and a perfect offset.

$CurrentCostPerOffsetTon_{perfect}$ = $CurrentCostPerOffsetTon_{sequest}$

Plugging in the perfect price result from the previous chapter results in

PriceOffset=

$$\frac{\sum_{t=0}^{T}((1-PermDisc)*PriceOffset*QuanOffset_t+PriceOffset*Buyback_t+MainCost_t)/(1+Disc)^t}{\sum_{t=0}^{T}(QuanOffset_t)/(1+Disc)^t}$$

In turn, if we divide through by the PriceOffset term and then solve for the permanence discount we get

$$\text{PermDiscount} = \frac{\sum_{t=0}^{T}(Buyback_t+MainCost_t/\text{PriceOffset})/(1+Disc)^t}{\sum_{t=0}^{T}QuanOffset_t/(1+Disc)^t}$$

The algebraic composition of this formula shows several things

- If there is no buyback program and no maintenance costs, then there will be no permanence discount.
- It is possible if the maintenance costs plus the buyback are too big relative to the price of the offset that the formula can yield permanence discounts in excess of one.
- When the buyback and maintenance costs are expressed in terms of the total volume of offsets generated during project life and one expresses the offset quantity in year t as fraction of total project offset then all terms would have total offset in them and this could be divided out. What really matters within the formula is the relative relationship between the buyback, maintenance costs and accumulation rate in terms of the total project cumulative offset. Furthermore as long as the items are set relatively the formula can be evaluated on a typical land unit basis (e.g. 1 acre) or on the basis of the total project yielding identical results.

The formula can be generalized to the case of non constant offset prices yielding

$$PermDisc = 1 - \frac{K * \sum_{i=1}^{T} (EP_t * QuanOffset_t) / (1+Disc)^t}{\sum_{t=0}^{T} CP_t * QuanOffset_t / (1+Disc)^t} + \frac{\sum_{t=0}^{T} (EP_t * BuyBack_t + MainCost_t / PriceOffset) / (1+Disc)^t}{\sum_{t=0}^{T} CP_t * QuanOffset_t / (1+Disc)^t}$$

where

$$K = \frac{\sum_{t=0}^{T} CP_t \ / (1+Disc)^t}{\sum_{t=0}^{T} EP_t / (1+Disc)^t}$$

In this formula the discount rises with higher future carbon prices and falls with escalating contract price terms.

2.2.2 Applications

In order to illustrate how this formula might be used, let us consider some cases. The cases will be in the context of a hypothetical agricultural soil carbon project involving conversion of conventionally tilled land to notilled land. The data for this are based on the offset accumulation pattern in figure 1 which was drawn from West et al. The relative quantities of carbon are scaled off of the figure and the total project offset is adjusted so that over the 24 year period in the average annual accumulation rate was 0.23 metric tones of carbon equivalent per acre (the West and Post average over some 267 agronomic experiments involving tillage changes). We will also use constant carbon equivalent prices. Thus, the price escalation terms for the carbon equivalent price and the contract price are set to one ($CP_t=EP_t=1$).

2.2.2.1 Discount in the absence of maintenance and leasing.

Suppose the project involves conversion from conventional till to no till and proceeds to pay for the accumulations over 24 years and upon equilibrium payments cease but farmers continue the practice as they find the reduced tillage system could be superior to returning back to conventional tillage (as is argued by many agronomists). In such a case, the practice continues indefinitely without the need for maintenance or buyback permanence considerations. Under such circumstances the permanence discount is zero and the offsets from the project are exactly equivalent to offsets from an emission based project.

2.2.2.2 Incidence of maintenance

Suppose that after the carbon accumulation ceases and soil equilibrium is obtained that the contract specifies a $5 per acre maintenance cost will be paid to the land owner to maintain the sequestered carbon from year 25 on. Under such circumstances the permanence discount is 36.32%. This implies the amount paid for the nonpermanent sequestration generated offset quantity would be 63.68% of the amount paid for a permanent offset.

2.2.2.3 Leasing the commodity

Suppose that lease terms are established where those generating the project offsets are paid for the offsets as they arise during the first 25 years but that at the end of the 25 year period the lease expires. Consequently, in year 26 the purchaser does not have any offsets they can rely on and must replace the total quantity of offsets generated during the project life by entering the marketplace and purchasing that quantity of offset at the market price. Under such circumstances the permanence discount is 47.19%. This implies the amount paid for the nonpermanent sequestration generated offset quantity would be 52.81% of the amount paid for a permanent offset.

2.2.2.4 Practice reversal

Suppose that the contract is established where those generating the project offsets are paid for the offsets as they arise during the first 25 years and at the end of the 25 year period, then the practice is allowed to be discontinued and the offset is released over a three-year period until it returns to the original equilibrium. Consequently, in each of years 26-8 the purchaser must replace one third of the total quantity of offsets generated during the project life by entering the marketplace and purchasing that quantity of offset at the market price. Under such circumstances the permanence discount is 45.40%. This implies the amount paid for the nonpermanent sequestration generated offset quantity would be 54.60% of the amount paid for a permanent offset.

2.2.2.5 Maintaining a mature tillage change

Many proposals have been made that suggest payments to offset producers who have begun the types of practices paid for under the project before project inception. For example, this would involves paying farmers who adopted reduced tillage practices in the years before a GHG program begins and that they be compensated for the offsets that they continue to accumulate. Let us evaluate such a case. Suppose that a project that coverts conventional till to no till has been in place for seven years and that one pays for the incremental offsets from today to year 17 and upon saturation then pays $4 in maintenance costs from years 18 to 100 to maintain the carbon in the ecosystem. Empirically, we set this up by removing the first seven years of offset accumulation from the data used in our earlier cases. Under these circumstances the calculated permanence discount is 98.86% or the willingness to pay would only be 1.14% of the permanent emission offset price.

2.2.2.6 Renewing the lease on a mature tillage change

It is possible that one may develop and operate a project under leasing arrangement and then be willing to renew the lease after the expiration of the lease. One possible case is that once the farmer has adjusted to using the no till practice, that the farmer may be willing to commit to a second leasing term of say 20 years without the need for maintenance costs as the practice is found to be economically superior. Thus let us consider a case where all of the accumulated carbon generated under a prior lease involving a conventional tillage to notill conversion is offered for an additional 20 year lease. Furthermore, suppose that no maintenance costs are required, but that the lease expires and thus involves a buyback at the end of the 20 year lease period. This examines the residual value of the stock of carbon developed under a lease providing it does not volatize at the end of the lease period. In this case the discount factor computes to be 43.88% o that one can sell the carbon for 56.12% of the market price.

2.3 Implementing Spreadsheet

The permanence discount formula discussed above was implemented in the workbook eddiscount.xls under component sheet called **permanence**. Conceptually, this sheet can be discussed in terms of four things: inputs, calculations, outputs and saved cases.

2.3.1 Inputs

Two different types of input are used in the program. The first one is portrayed in the screenshot below.

	A	B	C	D
1	**Basic Data**			
2	Discount/Interest Rate			4.00%
3	Contract price escalation rate			0.00%
4	Offset price escalation rate			0.00%
5	Carbon Price			30
6	Maintainence Cost			0
7	Begin Main Year			25
8	End Maint year			100
9	Maintainance Cost/ Price			0

This portion of the sheet is in the top left corner and contains the

- Discount rate - the real interest-rate used in calculating the present value of items.
- Carbon equivalent price per ton in the base period.
- Contract price escalation factor on a percentage per year basis. Entering 1% in this position reflects contract terms that escalate the offset price paid by the purchaser to the offset producer rise by 1% per year during the length of the contract.
- Offset price escalation factor on a percentage per year basis. Entering 1% in this position reflects market conditions and damage factors that escalate the market offset price by 1% per year during the entire 100 years.
- Maintenance costs, incurred on an annual basis, that are independent of quantity of offset produced and begin in the beginning maintenance year and end in the ending maintenance year.
- Beginning year in which the maintenance cost is first paid.
- Ending year which gives the last year in which the maintenance cost is paid.
- Calculated ratio of the maintenance cost to the carbon price.

The second segment of the input consists of the 100 year stream of carbon quantities, maintenance costs and buybacks with the first 10 years shown in the screenshot below

	A	B	C	D
15		---- **Annual Data on Project** ----		
16				
17				
18		Offset in		Buyback
19		Category	Maintain	Offset
20	**Year**	Sequest 1	Cost	Replace
21	0	0	0	
22	1	0.068	0	
23	2	0.17	0	
24	3	0.544	0	
25	4	0.884	0	
26	5	0.85	0	
27	6	0.646	0	
28	7	0.476	0	
29	8	0.34	0	
30	9	0.272	0	
31	10	0.238	0	

Four columns are shown in this data. They are the:

- ❖ Number of the year ranging from 0 which is today until 100 and will be used in calculating the discounted terms
- ❖ Yearly offset quantity which must be in consistent units with the offset price. These data give the added offsets produced in a given year which arise from the project and are not cumulative amounts.
- ❖ Yearly maintenance costs which must reflect the total maintenance costs paid to a project of the scope and size of the one generating the offset quantities. This maintenance cost is assumed to be paid annually in each year following between the specified starting and ending maintenance cost years as specified in the first input data set above. Formulae have been added in the spreadsheet that start and stop this payment. Users may choose to replace those columns with whatever data are appropriate if a non-constant maintenance cost is relevant.
- ❖ Annually incurred needed buybacks of offsets needed when sequestered offsets are released and the buyer must purchase. The must be in the same units as the offset quantities. When portraying leasing, this input reflects a buyback of the total offsets produced in the year following the lease.

2.3.2 Calculations

In order to calculate the discount quantities appropriately, a number of calculation columns are added. The first 10 years of these are shown in the screenshot just below

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
18														
19		**---- Annual Data on Project ----**				**----------------------------- Annual Calculations ------------------------------**								
20									PV					
21							Contract	Offset	Annual					
22		Offset in		Buyback			Price	Price	Cost	PV	Discount	Discount		PV
23		Category	Maintain	Offset		Discount	Multiplier	Multiplier	without	Annual	Numerator	Numerator	Discount	with
24	**Year**	Sequest 1	Cost	Replace		Factor	Factor	Factor	Discount	Offset	1	2	Denominat	Discount
25	0	0	0			1	1	1	0	0	0	0	0	0
26	1	0.068	0			0.961538	1	1	1.9615385	0.065385	0.065385	0	0.065385	1.030674
27	2	0.17	0			0.924556	1	1	4.7152367	0.157175	0.157175	0	0.157175	2.477582
28	3	0.544	0			0.888996	1	1	14.508421	0.483614	0.483614	0	0.483614	7.62333
29	4	0.884	0			0.854804	1	1	22.669407	0.755647	0.755647	0	0.755647	11.91145
30	5	0.85	0			0.821927	1	1	20.959141	0.698638	0.698638	0	0.698638	11.01281
31	6	0.646	0			0.790315	1	1	15.316296	0.510543	0.510543	0	0.510543	8.047821
32	7	0.476	0			0.759918	1	1	10.851626	0.361721	0.361721	0	0.361721	5.701898
33	8	0.34	0			0.73069	1	1	7.4530401	0.248435	0.248435	0	0.248435	3.916138
34	9	0.272	0			0.702587	1	1	5.7331078	0.191104	0.191104	0	0.191104	3.012414
35	10	0.238	0			0.675564	1	1	4.8235282	0.160784	0.160784	0	0.160784	2.534483

The major columns of this are

- ❖ Discount factor -- present value of a dollar received in year N which is an evaluation of $1/(1+Disc)^N$
- ❖ Contract price multiplier factor -- this is the extrapolation of the contract price multiplier which is the term $(1+CP)^N$ where CP comes from cell D3 of the spreadsheet.
- ❖ Offset price multiplier factor -- this is the extrapolation of the offset price multiplier which is the term $(1+EP)^N$ where EP comes from cell D4 of the spreadsheet.

- PV annual cost without discount -- This is the present value of the total cost incurred in a particular year without use of the permanence discount. This is calculated in each year by multiplying the offset price times the relevant yearly offset quantity plus the offset price times any needed buyback quantity plus the maintenance cost. Then this sum is discounted back to present value.
- PV annual offset -- this is the present value of the offset quantity incurred in each year. This is calculated for a year by taking the quantity of offset accrued under the project multiplied by the discount factor to get it into present terms. This quantity does not include the buyback quantity is that constitutes an expenditure outside the project are only trying to value increments within the project.
- Numerator1 -- this is the annual evaluation of the first term $(EP_t * QuanOffset_t)/(1+Disc)^t$ in the numerator of the discount formula
- Numerator2 -- this is the annual evaluation of the second term $(EP_t * BuyBack_t + MainCost_t / PriceOffset)/(1+Disc)^t$ in the numerator of the discount formula
- Denominator -- this is the annual evaluation of the term $CP_t * QuanOffset_t /(1+Disc)^t$ in the denominator of the discount formula
- PV annual cost with discount -- This is the present value of the total cost incurred in a particular year with use of the permanence discount. This is calculated in each year by multiplying one minus the permanence discount times the offset price times the relevant yearly offset quantity plus the offset price times any needed buyback quantity then adding in the maintenance cost and discounting this total sum back to present value.

2.3.3 Outputs

Three major classes of outputs are created by the program as shown in the screenshot below

	A	B	C	D	E	F	G	H
1	**Basic Data**					**Results without discount**		
2	Discount/Interest Rate			4.00%		NPV Cost		187.9484
3	Contract price escalation rate			0.00%		NPV Carbon EQ		4.248694
4	Offset price escalation rate			0.00%		Present cost/ton		44.23675
5	Carbon Price			30				
6	Maintainence Cost			0		**Results with discount**		
7	Begin Main Year			25		NPV Cost		127.4608
8	End Maint year			100		NPV Carbon EQ		4.248694
9	Maintainance Cost/ Price			0		Present cost/ton		30
10								
11	**Discount calculation**							
12	**K**		1					
13	Discount Numerator1		4.2486941					
14	Disount Numerator 2		2.0162528					
15	Discount Denominator		4.2486941					
16	**Permanence Discount**		**47.46%**					
17	**Price Percent**		**52.54%**					

- Discount formula evaluation -- the discount calculations involved with evaluating the discount formula derived above appear in Column C rows 16 and 17 in the solid box above. Those results in turn use the two numerator terms, the denominator term long and the K factor computed in Column C rows 12-15. The permanence discount is formatted into percentage terms. In this case it is 47.46%. Finally calculation is done of the percentage of the equivalent emission price equaling one minus the permanence discount.
- Results without discount – calculations in column G rows 2-4 in the box made of dots where we calculate how much would be paid for the prospect if there was no permanence discount. This gives the net present value of the cost paid in the absence of a permanence discount divided by the offset quantity. Both of these items are computed by summing up the annual amounts of these. This shows that, under the portrayed circumstances, while $30 was paid per ton of carbon that the maintenance cost raised the effective price to $44.23.
- Results with discount -- where we calculate how much would be paid for the prospect if the permanence discount were in effect as reported in the box with the large dashes. This consists of the net present value of the cost paid in the presence of a permanence discount divided by the offset quantity. This result will equal the original offset price in the presence of contract (CP) and price (EP) escalation terms equal to one and is not in general equal to that when other values for those terms are present.

2.3.4 Saved cases

Finally the spreadsheet contains the data for the cases used in the application section above. These appear in columns P-AR in the first 125 rows.

2.4 Blending multiple offset categories

A project may well involve multiple categories of offsets each with different permanence characteristics. In such case, one needs need to evaluate the discounts that arise for the different components considering their differing permanence characteristics. Consequently, an evaluation would often show sequestration offsets incurred a permanence discount, but no discounts for emission offsets from say reduced usage of fuel or fertilizer that lead to lower amounts of carbon dioxide or nitrous oxide emissions.

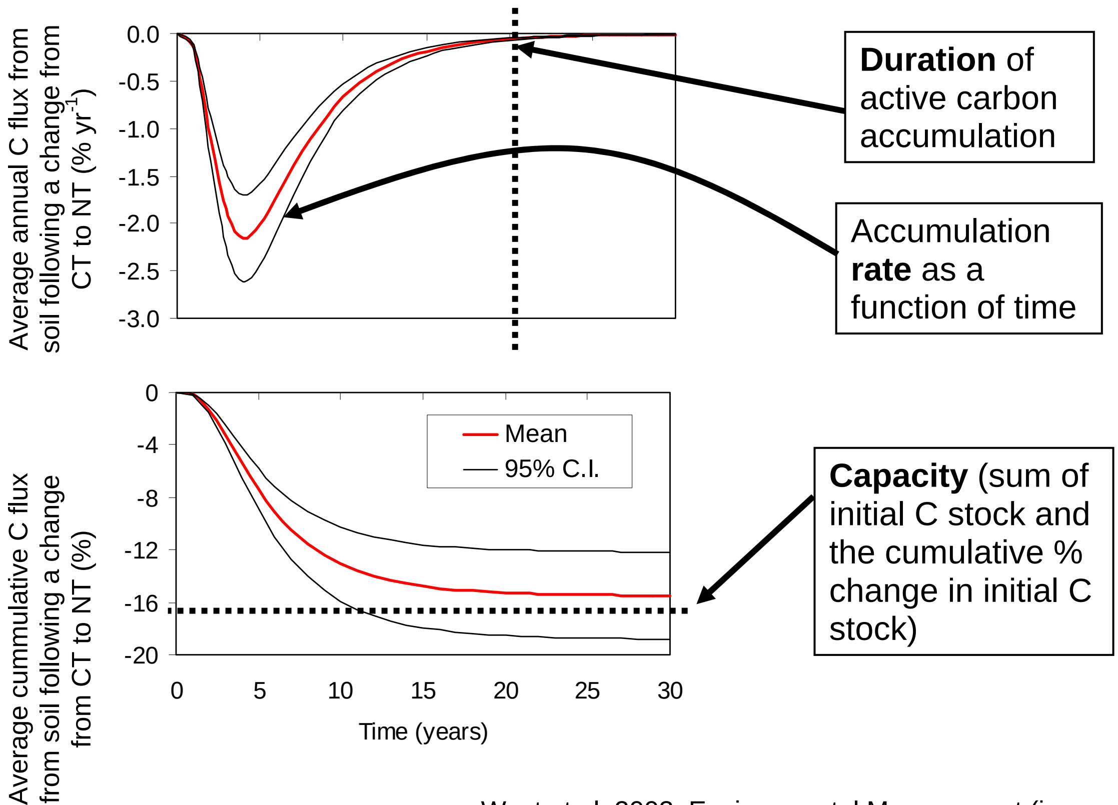
2.5 Summary

A permanence discount formula was derived. This formula reflects the differential characteristics induced by permanence attributes including

- Limited duration of available offsets,
- Offsets arising in different quantities over time,
- Maintenance costs that may be needed to keep offset assets in place and
- The need for buyers to enter the marketplace at a later time because of less than permanent contract terms or harvest induced emissions.

The permanence discount indicates the amount that the offset price would be reduced to reflect the alternative characteristics of the nonpermanent offset as they influence the value the purchaser receives from owning that offset.

Figure I West et al's depiction of soil carbon time accumulation



West et al. 2003. Environmental Management (in press).

3 Assessing Uncertainty

The second discounting question involves the magnitude of the wedge between the purchaser and the producer arising because of uncertainty in the quantity of potential offsets produced by a project. Under many environmental trading schemes penalties are imposed for participants who exhibit emission levels that exceed environmental commitments. For example, such penalties are imposed within the sulfur dioxide trading scheme implemented in United States. Generally, the imposed penalties are a factor of ten or more times the market price of emission rights. This creates substantial interest on behalf of the purchaser directed toward ensuring that the potential offset credits acquired can be safely relied upon to exceed the environmental commitments.

In the sulfur dioxide trading scheme, penalties are specified by the regulatory agency. In the GHG offset trading there is the likelihood that international, national and or contractual penalties will be imposed for failing to reach commitments. Furthermore, one should recognize that within the land-use case it is likely that the quantity of offsets produced by any individual landowner will be small relative to the purchaser's needs. Thus, it is likely that while shortfall penalties will be imposed at the level of the emitter by the regulatory agency, that the emitter in turn would pass them on to offset producers or offset aggregators through contract terms.

In the face of shortfall penalties, it is likely that the uncertainty in offset quantity created by natural climatic and sampling uncertainty will cause either

- ❖ purchasers to take deliberate actions to assure that they will not have offsets that are smaller than the level claimed under the attainment of the environmental commitment; or
- ❖ policy programs which mandate something like a conservative creditable level given in offset. For example, in the Kyoto negotiations, Canada proposed that the quantity credits that would be accepted from a project would be a level that one is 90% sure would be met or exceeded.

The deliberate action generally involves either acquiring more offsets than are needed or acquiring some other form of insurance (Subak, 2003, Wong and Dutschke, 2003).

This then implies a discount manifest in either:

- ❖ Reduction in the offset quantity permitted to be credited and thus sold so that the potential offset quantity is reduced to a creditable level such that one is, for example, 90% sure that a level quantity equaling that much or more will be produced.
- ❖ Reduction in the price paid by the purchaser per average ton so it is multiplied by one minus an uncertainty discount factor. That uncertainty discount factor would be the percentage reduction in the mean amount of offsets needed to yield the offset quantity that is produced with the appropriate confidence.

Here we will derive an uncertainty discount which could be applied to the quantity offered for sale or the price. Four main issues present themselves in terms of the development and empirical specification of this approach.

- What is the theoretical approach for computing the discount?
- On what geographic and temporal basis should the uncertainty magnitude be estimated?
- How do you compute the empirical description of the magnitude of the uncertainty associated with a prospect?
- What is the exact formula for the discount quantity?

Each of these issues will be discussed below, then we will discuss applications, a spreadsheet implementation, and the revision of the uncertainty measure as a project evolves.

3.1 Discount calculation: theory to practice

If we return to our general discount formula where we equate the costs per unit

$$\text{CurrentCostPerOffsetTon}_{\text{perfect}} = \text{CurrentCostPerOffsetTon}_{\text{other}}$$

Under constant carbon prices and contract prices we get

$$\text{OffsetPrice}_0 = \frac{\sum_{t=0}^{T} (OffsetPrice_0 * (1 - PrDiscount) * QuanOffset_t + OtherCost_t)/(1+Disc)^t}{\sum_{t=0}^{T} ClaimQuanOffset_t/(1+Disc)^t}$$

Now let us particularize this to an uncertainty only case. Let's suppose that there are no maintenance costs and that the amount in the denominator is the claimable offset quantity that the purchaser wishes to be a confident will exceed the amount required with a given probability. In such a case, if we wish to be for example 90% sure that the credits claimed in the denominator exceed the amount required then one can compute this amount using a conventional statistical confidence interval approach. Namely, under the assumption of a normal distribution (the basis for which we will discuss below) one can compute a level of offset that will be exceeded a given percentage of time. The formula for a statistical confidence interval is

ConfidentLevel = Mean - Multiple(DesiredConfidence) * StdError

where

ConfidentLevel is the level of offsets one can be confident will be exceeded with a statistical based desired confidence level.

Mean is the average level of the offset attained from the prospect at hand.

Multiple(DesiredConfidence) is the multiple from standard statistical theory and is a function of the desired confidence interval. For example, use of a multiple equal to 1.96 under an assumption of a normal distribution is equivalent to assuming that the credits that are claimable are 97.5% sure to be met or exceeded.

StdError is a measure of the standard deviation of the offsets created under the project computed by traditional statistical methods.

Alternatively this can be expressed in terms of the coefficient of variation (CV) which is the standard deviation divided by the mean

ConfidentLevel = Mean * (1 - Multiple(DesiredConfidence) * CV)

or

$$\text{ClaimQuanOfffset} = \overline{QuanOffset_t} * (1 - Z_\alpha * CV_t)$$

Where

$\overline{QuanOffset_t}$ is the mean level of project generated potential offsets in year t.

CV_t is the coefficient of variation of offsets generated by the project in year t.

Z_α is the multiple from the normal distribution table that reflects a confidence interval established with probability α. For example, when setting α = 90% under a one tailed test then this value equals 1.28.

In turn substituting in the above formula becomes

$$\text{OffsetPrice}_0 = \frac{\sum_{t=0}^{T} (OffsetPrice_0 * (1 - UncerDiscount) * \overline{QuanOffset_t}\ ) / (1 + Disc)^t}{\sum_{t=0}^{T} \overline{QuanOffset_t} * (1 - Z_\alpha * CV_t) / (1 + Disc)^t}$$

When the CV is assumed constant from year to year, then this equation when solved yields an uncertainty discount

$$\text{UncerDisc} = Z_\alpha * CV$$

being a function of the Z_α multiple reflecting the α percentage safety margin one needs to meet and the coefficient of variation (CV). Figure one illustrates this situation.

If the coefficient of variation varies and one incorporates varying contract and offset prices then the uncertainty discount becomes

$$\text{UncerDisc} = 1 - \frac{\sum_{t=0}^{T} CP_t / (1 + Disc)^t}{\sum_{t=0}^{T} EP_t\ / (1 + Disc)^t} * \frac{\sum_{t=0}^{T} EP_t * QuanOffset_t * CV_t / (1 + Disc)^t}{\sum_{t=0}^{T} CP_t * QuanOffset_t\ / (1 + Disc)^t}$$

3.1.1 Why normality

Above we used a normality assumption in the calculation. The reason for this arises from the central limit theorem from statistics. In particular, a purchaser will likely buy a large quantity of offsets arising over a number of years. As a consequence, the offset quantity acquired by a purchaser would be the aggregation of numerous contributions from many individual land units attained over a number of years. Statistically, the uncertain quantity can be viewed as the sample mean across a geographic and temporal population of offsets produced. The central limit theorem holds that the distribution of sample means for independent samples is normally distributed.

If one wishes to use something other than normality than one would either

- ❖ Make an alternative distributional assumption and compute the confidence interval based on that assumption.
- ❖ Come up with an empirical distribution and find a level of discount relative to the mean that would ensure the particular confidence interval that was to be attained.

3.2 What is the uncertain quantity?

The coefficient of variation needed within the above formula is the relative proportion that the standard error of the potential project offset is of the mean project offset. A coefficient of variation of 0.10 implies that the standard error is 10% of the mean. Some evidence exists that indicate that coefficients of variation may be large. A soil scientist at a recent meeting argued that the coefficient of variation for soil carbon for a particular field trial is generally about one, meaning that that the standard deviation about equal to the mean. This would imply that the uncertainty discount would completely overwhelm the salable quantity of offset. However, offset sales do not occur at the individual plot level.

Purchasers will generally be interested in a quantity of total offsets that occur over multiple years and land units. For example, a contract might be set up for 100,000 tons in each of five years. In such a case, the liability for the shortfall would not arise from plot level variation in offset quantity, but rather across all of the time periods and land units in the contract. This would involve aggregating over substantial land areas. It is not uncommon to hear arguments that the potential offset rate arising from an afforestation project is somewhere around one metric ton per acre while the potential offset rate arising from a change in crop tillage practices is somewhere in the neighborhood of a quarter of a metric ton per acre. If, in turn, an aggregate project was formulated to deliver 100,000 tons per year this implies participation of 100,000 forest acres or 400,000 agricultural acres. Given such potential magnitudes of contract participation, it is certainly relevant to say that the uncertainty discount should arise relative to an aggregation over both time and space.

Statistically, the mean of an offset distribution arising across multiple places and multiple times would be the sum of the means of the offset distributions from each individual place during each individual time period. The composite standard deviation computation is more complicated. If one considers just two plots, the variance (which is the square of the standard deviation) of the joint offset distribution across the two plots is equal to the variance on the first plot plus the variance on the second plot plus twice the correlation coefficient between the two plots times their respective standard errors. This implies that if you take two equally sliced sized plots with equal standard deviations that the standard deviation of total offset production across the two plots will be

- Twice the standard deviation on the individual plots if the two plots are perfectly correlated.
- Zero if the two plots are perfectly negatively correlated.
- The square root of two times the standard deviation if the production on the plots were truly independent.

Statistical results on the standard deviation of the sample mean across independent observations imply that the standard deviation of a total contract will become smaller with aggregation. In particular, the standard deviation of the total portfolio mean is the standard deviation of the individual observations divided by the square root of the sample size.

Kim investigated the reduction of variance due to aggregation in the context of crop yields that are generally felt to be related to carbon input. He found that when the standard deviation was calculated based on crop simulation results for a single plot one finds a 45% coefficient of variation leading to about a 90% uncertainty discount factor. However, when one uses a farm level data which aggregates plots then using information derived by crop insurance investigators he found the farm level coefficient of variation falls to somewhere around 35% of the mean. In turn if one expands to

- County level then the coefficient of variation is about 27%
- Crop reporting district level then the coefficient of variation is about 17%
- State level then the coefficient of variation is about 15%
- National level then the coefficient of variation is about 6%

One should also do the calculation over time. On a single year basis, the coefficient of variation for annual soybean yields at the crop reporting district level is 18%. If one looks at total production over two years the coefficient of variation falls to 11%, to 8% over 3 years, 7% over 4 years and 5% over 5 years. This certainly indicates the coefficient of variation on cumulative production during five-year project may be one third or more smaller than what would occur in an annual contract.

The results in table 1 show the consequences of combining both temporal and spatial aggregation. The results show the importance of the aggregation with basically a tenfold reduction in the uncertainty discount when one looks cumulatively across time and space.

3.3 How big is the uncertainty

The next important question involves how one should quantify the magnitude of uncertainty for a particular offset project. Namely what approaches can be used to develop a relevant coefficient of variation estimate for the scope of the project at hand. The complicating factor is that one must estimate the coefficient of variation not at the sample plot level but must properly look the effect of temporal and geographic aggregation. Three methods conceivably can be used to do this involving use of (1) land use based GHG offset simulation models, (2) field sampling and measurement, and (3) proxy historical data. Each is discussed below.

3.3.1 Land use based GHG offset simulation models

Certainly within the agricultural arena there are widely known and used land use based GHG offset simulation models. These include the CENTURY and EPIC models as well as a number of others. Such models can be run over varying weather, soil, and crop management conditions to obtain a distribution of GHG offset production levels. By running a model repeatedly across the distribution of weather events, one can obtain an estimate of the variance in offset rates. One can also look at the effect of cumulative offset rates over years by running the model for say 25 years and computing the coefficient of variation for 5 year total offset production aggregates instead of single year data.

In our judgment, a major problem arises in properly obtaining a coefficient of variation estimate using simulators. Namely it is difficult to properly include the variation reducing aspects of less than perfectly correlated offsets across the landscape. Namely, it is reasonable to believe that across individual sites on a farm and across farms there will be a mixture of both unique localized events and correlated weather. For example, hail may be localized, but temperature and frontal rains may affect most of a county. On the other hand, computer models also ignore a number of localized factors. For example, CENTURY simulates forests but does not handle events such as localized wind damage, pest outbreaks, human and wildlife induced damage, soil and topography variation and lightning strikes among many other factors. This implies underestimation of the coefficient of variation on a plot.

Furthermore, when running with stochastically generated weather it would be difficult to obtain the proper weather event correlation across areas and geographic areas. Simulators would certainly ignore a number of other less than perfectly correlated localized events such as those mentioned for the forestry case just above. One may be able to get variance estimates for the simulated sites, but it would be difficult to properly incorporate spatial correlation across sites. A potential approach is to use historical weather simultaneously at all plots and correlate the results by year thus incorporating the spatial correlation arising across multiple weather stations. Even this can be problematic as the number of weather stations on which one can obtain data within a region is limited often one or two observations for a county and may be of limited duration.

As discussed above, the fall in variation from a plot level to a farm level to a county can be substantial and key to obtaining a small variability discount. Furthermore, there would not be data on localized pest, soils, storms etc which would have dramatic effects on different plots but would tend to cancel out across multiple plots.

This implies that land based GHG offset simulation models will likely underestimate variance at a site and be difficult to use to obtain data on the proper special correlation across a contract. A reasonable approach may be to develop the coefficient of variation estimates from simulation models then adjust the coefficient of variation estimate both at the plot level and as it aggregates across space and time based on a proxy approach. For example, one could assume that observations on how crop yield deviations are reduced when one aggregates across a geographic area are also true of GHG offsets.

3.3.2 Field measurement

The other obvious alternative for estimating the coefficient of variation involves the use of field measurements. Namely, one can measure carbon stock at alternative locations and do other measurements relative to methane, nitrous oxide and carbon dioxide emissions. The difficulty with field measurement is that it cannot really be done before the project is implemented and will not be available until sometime after the project has begun (i.e. to measure the five-year stock one must wait for five years) unless highly similar projects appear within the same region. Clearly, such measurements will provide a valuable check on apriori estimates and, if employed, will provide a basis for revising the estimates later during the project life. It may also be difficult to have a large enough sample to accurately estimate the variance reducing properties of the diverse spatial scale of a contract.

Again measurement may need to be complemented with other data to fully incorporate spatial characteristics much as discussed in the above simulation section.

3.3.3 Proxy historical data

The final possible approach and the one recommended for apriori cases herein involves the use of proxy historical data for the coefficient of variation. Namely, statements have been made by soil scientists that the carbon inputs to the soil are a function of plant size. In turn, crop yield is also a function of plant size. Thus, it could be argued that carbon inputs are largely a function of crop yield (Kim investigated the correlation between carbon gains and crop yield finding the correlation coefficient varies from 0.70 to 0.93 based on EPIC simulations). Thus, one could assume that the variation in carbon inputs can be proxied by the variation in crop yield. Namely, one could estimate the coefficient of variation exhibited in commonly available spatially and temporarily distributed crop yield data and then apply the coefficient of variation there from in the discount calculation.

Crop yield data are widely available from various USDA sources. The National Agricultural Statistics Service releases annual crop yield data on a county, regional, state, and national basis through the web site http://www.usda.gov/nass/pubs/histdata.htm. Cross-sectional data is also available at the sub county level through the USDA National Resource Inventory as discussed at http://www.nrcs.usda.gov/technical/NRI/. However such data are not annual time series appearing every 5 years and would need to be supplemented with multiple year data.

Coefficient of variation data based on historical yield estimates appear in table 1. We recommend that the coefficient of variation used in the uncertainty discount for agricultural projects be drawn from somewhere between the county and crop reporting district data. This would imply that the coefficient of variation is in the neighborhood of 5%. As of now I do not know where to get any such data for forestry.

3.4 Applications of Discount formula for Uncertainty

As derived above the uncertainty discount formula is

$$\text{UncerDisc} = Z_{\alpha} * \text{CV}$$

Under corficients of variation (CVs) of 5% and 10% the uncertainty discounts are

Confidence Level	Multiplier from Normal Distribution Z_{α}	Discount given a Coefficient of Variation (CV) of	
		5%	10%
80%	0.84	4.21%	8.42%
85%	1.04	5.18%	10.36%
90%	1.28	6.41%	12.82%
95%	1.64	8.22%	16.44%
99%	2.33	11.63%	23.26%

Such a discount shows the following

- The less accurate the measurement of standard error the larger the uncertainty discount. Thus, there are incentives to reduce the size of the standard deviation by improving measurements.
- The broader the aggregation the smaller the coefficient of variation and the consequent uncertainty discount. Thus, aggregators have incentives to try to reduce the coefficient of variation by composing a portfolio of offsets that tends to cancel out risk. As a consequence it may be desirable to mix different types of land based strategies or include some land and some other strategies in order to reduce variation and the consequent discount.
- The appropriate probability level for use in specifying the confidence interval is likely not a choice item for the producer but is probably ultimately imposed within the regulatory scheme or by the purchaser.
- Producers may wish to set higher confidence intervals on their offset sales as marketing strategies to assert they have a higher quality product. However, as the above table demonstrates the higher the confidence interval the more GHG offset must be produced on average and the safety margin increases in a nonlinear fashion with certainty level.

3.5 Choice of uncertainty level for the purchaser or regulator

There is obviously a trade-off that a producer or regulator faces in selecting the appropriate probability level. The closer the probability level is to 50% or the average offset level the less the deviation between average potential offsets and safe, claimable offsets and since all offsets will cost money to produce the lower would be the cost of acquiring the offset. However, the closer the certainty probability level is to 50%, the greater the incidence that shortfalls will be observed and in turn the greater the likelihood that shortfall penalties will be incurred. Decision-makers implicitly need to establish a trade-off between the expected shortfall costs and the expected costs of acquiring the offsets. One can formally evaluate this trade-off using the data from the table above where moving from a 90% to a 99% confidence interval reduces the long run expected shortfall costs by 9% by the increases the amount of potential offsets that must be produced by about 5%. One can examine the size of shortfall penalties and decide where this trade-off should be set.

3.6 Implementing Spreadsheet

The uncertainty discount formula discussed above was implemented in the spreadsheet workbook eddiscount.xls under the component sheet called uncertainty. A screenshot of the uncertainty sheet is just below

	A	B	C	D	E	F	G
1							
2							
3	Probability		80%	85%	90%	95%	99%
4	Multiplier		0.841621	1.036433	1.281552	1.644854	2.326348
5							
6	Mean		120	120	120	120	120
7	Std Dev		6	6	6	6	6
8	CV		5.00%	5.00%	5.00%	5.00%	5.00%
9							
10	Discount		4.21%	5.18%	6.41%	8.22%	11.63%
11							
12	Salable Amount		95.79%	94.82%	93.59%	91.78%	88.37%
13	Discounted Amount		114.95	113.78	112.31	110.13	106.04
14							

Within the worksheet the main input items are the

- Probability appearing on line 3.
- Coefficient of variation(CV) appearing on line 8 (in this case the coefficient of variation is computed by specifying the mean in line 6, the standard deviation in line 7 then dividing the standard deviation by the mean to get the coefficient of variation in line 6)

In turn, we compute the multiplier in line 4 based on a normal distribution assumption by using the Excel function -NORMINV(1-Probability,0,1) which draws the negative of the multiplier needed from the standardized normal distribution (which has mean zero and standard error one).

Finally we compute the

- Uncertainty discount in line 10
- Creditable fraction of the potential offset in line 12 (or equivalently the percentage that the received price would be of the market price when applied to the average amount of potential offset)
- Total quantity of GHG offset produced per unit of creditable offset in line 13

3.7 Revisiting uncertainty as a project matures

We recommend above that the uncertainty discount be calculated based on a proxy approach when the project is being formulated and negotiated. Nevertheless, it is certainly desirable to revise the estimates of project potential offset production as the project matures. Namely, after the project has been in place for five years one could take measurements and develop estimates of the observed quantity of offsets produced as well as their standard error. Such estimates could be used in reformulating the mean offset rates and discounts used in the project contract. In turn, it would likely be in the interests of both parties to have some formal revision process on say a five-year interval that would allow revision of the uncertainty discount and the creditable proportion of potential offsets.

3.8 Handling multiple offsets with differing characteristics

The uncertainty discount was applied to the project potential offset on a uniform basis. However, a project is likely to create different offsets with different uncertainty characteristics. For example, one may be very certain of the reduced methane from manure treatment practice changes and thus has virtually no uncertainty in terms of saved methane emissions but would-be much less certain about the amount of carbon sequestered in the soil. As a consequence, one should not apply the same uncertainty discount to all of the offsets created by a project but rather should separate the accounts into different classes with essentially identical characteristics. Subsequently, one would calculate individual discounts then unify results from all the classes and their particular discounts in a total economic analysis within the project proposal and reporting documents.

3.9 Summary

An uncertainty discount formula was derived. This formula reflects the differential characteristics induced by uncertainty attributes including

- The degree of variability inherent in the potential offsets created by the project relative to the average amount of potential offsets produced,
- The desired degree of confidence that the creditable offset quantity has to exhibit.

We recommend that the uncertainty be described in terms of the coefficient of variation and that the coefficient of variation initially be developed based on observable proxy data for yields of conventional products like crops or trees that can be observed using secondary data. Later during the project life such estimates can be refined based on field measurements.

The uncertainty discount exhibits several characteristics

- The larger the aggregation over time and space the smaller is likely to be the uncertainty discount. Added time and spatial dimensions tend to reduce total variation.
- The discount encourages precision as the smaller the variation estimation process the less the uncertainty discount.
- The calculated uncertainty discounts fall in a neighborhood of 5% to 10%

Figure 1: Portrayal of uncertainty discount

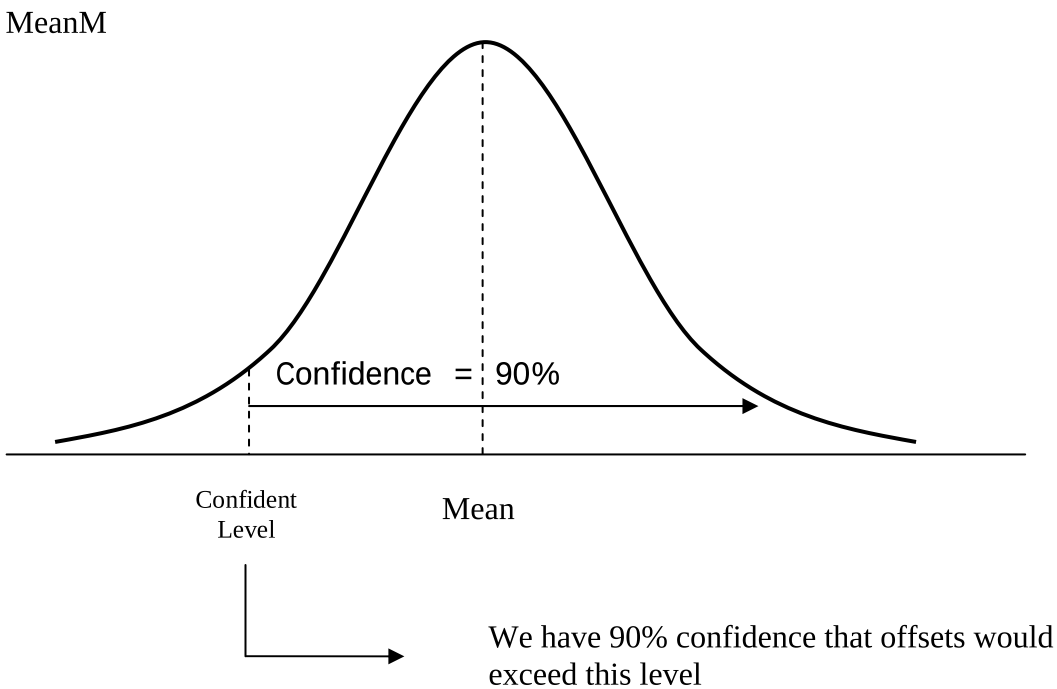


Table 1: Coefficient of variation for five-year cumulative yields of six crops at various geographic scales

	Sorghum	Corn	Rice	Wheat	Upland Cotton	Soybean	Average
US	1.33	4.59	2.01	4.30	1.49	2.51	2.71
State(Texas)	3.31	2.76	2.24	5.17	3.28	3.91	3.45
Crop District	2.88	5.96	2.30	5.68	5.93	5.44	**4.70**
County	3.46	4.48	1.05	N/A	6.87	10.76	**5.52**

4 Additionality and baselines

One prominent concept arising in the international GHG emission limit and implementing policy debate is known as additionality. This involves determination of the extent to which project interventions lead to GHG emission reductions that are additional to "business as usual" (UNFCCC, 1995; UNCCCS, 1997; Baumert, 1999).

The basic **additionality** concern in a nutshell is inherent in the often espoused position that:

> *Offset credits should only be granted for actions that are truly additional to what would have happened anyhow.*

Let us illustrate this. Suppose a National Park was established with many new trees planted before the beginning of a GHG program. Under strict additionality, those interested in offsetting global emissions would not permit the GHG offsets created by the growth of the preexisting National Park trees to be claimed as offset credits. They would say that the National Park establishment decision was made before the GHG program began and the embodied offsets would have occurred anyhow. Such credits would be argued to be not additional in the sense that they were not stimulated by the GHG program.

A highly associated concept is that of the **baseline**. A baseline projects what would happen in the absence of the GHG program under what is commonly called "business as usual". The baseline projects the current level of emissions and sequestration within the region at hand into the future. It takes into account future emission and sequestration arising from activities pursued in the absence of a GHG program like alterations in forestry activity, changes in crop tillage etc. Establishment of a baseline is a key component of the additionality concern, as the contributions which are truly additional are those that are above and beyond those within the baseline.

The implementation of a GHG project requires the establishment of both with and without project projections of net GHG emissions. The without project case provides the baseline. In turn, the computed difference between the with project case GHG potential offsets and the baseline, without project case GHG offset trajectories yields the quantity of creditable offsets generated by the project.

This section discusses the twin concepts of additionality and baseline formation. First, we focus on baseline estimation. Then we address estimation of the additionality discount.

4.1 Baseline establishment

Establishment of a baseline is difficult because it requires quantification of the future. This involves projection of regional activity under future unknown market, technological, production, population and environmental conditions. Adding to baseline formation difficulty is the fact that the baseline describes a future that, under implementation of the project, will not ever occur, being a hypothetical "without project" world that will never exist so it is not possible to observe one's errors and do better in the future.

4.1.1 Philosophical approaches to baseline establishment

A number of fundamental approaches may be taken toward baseline establishment. Each will be individually discussed below.

4.1.1.1 All is additional back to the beginning of the adoption of practices

One view that can be taken is that the future baseline does not contain any of the project promoted practices and that the implementation of those practices only displaces practices that would not have led to a change in GHG emissions. Under this view all project induced activities are additional and thus generate fully claimable offset credits.

A version of this view extends eligibility to land areas within the project domain that were converted to the practice somewhere in the past. This is typically justified from one of two viewpoints.

- ❖ The argument that the world faces eminent reversal of the previously adopted practices and so does the baseline. Under this argument, paying past adopters to continue their practices is justified since the business as usual baseline for the future entails project reversals. The most prevalent arena in which this argument is advanced involves avoided deforestation. Therein credits would be issued for the amount that existing carbon stock and other embodied GHG offsets in a standing forest exceed the GHG offsets encountered in switching to and maintaining a commonly used deforested land-use. The argument that is that in the absence of avoided deforestation payments that the land-use would change. Justification of this stance would require a baseline that contains a projection of deforestation or more generally increased emissions due to practice reversal.
- ❖ The second line of justification asserts that there are important other co-benefits that arise from practices like improved wildlife habitat, reduced erosion, improved water quality etc. Under this argument, past adopters should be compensated for these benefits under the guise of an offset program. This involves paying past good actors like farmers that have been using improved tillage for some time. This argument can be related to the baseline by combining it with the eminent reversal argument saying that if individuals are not compensated to the future the baseline will contain emissions when practices are discontinued.

4.1.1.2 The current state is the baseline -- nothing will change in the future

This argument asserts that the project area is in land-use equilibrium and that there will not be future practice changes. Namely, under business as usual, this view asserts that conditions observed just before project beginning will persist indefinitely without change. Thus, all new activities stimulated by the project generate additional offsets. Justification of this view requires evidence that the current land-use and associated practices are in equilibrium.

This practice equilibrium stance may be coupled with a forward projection of changes in GHG emissions based on the maturation of land-use practices observed at project beginning. For example, the baseline might involve projection of the future offset consequences of recently adopted tillage practices or recently planted immature forests. However, some take the stance that all of such changes are additional.

One can also adopt a baseline stance that asserts there will be no future changes in net GHG offsets and that the region is in practice and GHG offset equilibrium. The justification for this position would have to be that in the project area the evolution of land-use/practices would cause emissions that would balance off any anticipated offset gains. In particular, suppose the project region contains a fully regulated forest managed with even aged management. In such a case, one could argue that the GHG offsets were in equilibrium and that matching the regional area of young forests is an equal land area of mature forests that eminently will be harvested. Thus, if one looks in the next period one would see that the young forest had aged and sequestered more carbon but that the land holding the previously mature stand had been harvested releasing carbon and now fell into the youngest age class.

4.1.1.3 A proportion of project activity occurs in the future baseline

The project region may exhibit a degree of business as usual adoption of the project practice. For example, suppose a South Texas project was proposed that transforms rice acreage to pasture reducing rice methane emissions and increasing carbon sequestration. The baseline formation exercise for such an activity would find that there has been substantial historical reduction of rice acreage and that the prospects are that the land conversion will continue into the future. Thus, it would be likely that the baseline would have some business as usual rice land reduction. Similarly, in the last few decades across the United States there have been gains in forested acreage and afforestation projects might have baselines reflecting business as usual levels of afforestation.

Construction of a baseline containing some level of future adoption of the practices employed within the project introduces the concept of <u>partial additionality.</u> Therein some part of the project is acknowledged to inevitably happen under business as usual. For example, cases could arise where project activity is estimated to create a gross offset rate, but that the additional amount from the baseline is only estimated to be 95% of the gross project offset rate with 5% of the offsets estimated to have occurred under business as usual.

4.1.1.4 None of the prospective project activity is anticipated in the future

The final philosophical approach to baseline formation is that none of the project activities are present in the business as usual baseline. Under such circumstances, all project activity is additional. The argument is that the project activity that is proposed is totally additional since it has not been observed in the region and will not be adopted now or in the future in the absence of GHG offset payments. This is often bolstered by the observation that the activity is currently less profitable than existing alternatives and will remain so in the future.

4.1.2 Defining the extent of a baseline

A number of statements can be made regarding the extent of activity and time which the baseline should cover. Fundamentally, a baseline should

- ❖ Not be solely limited to the exact lands in the project area if there are highly similar lands in the surrounding region. This is especially true if the non-project lands have been subject to project like activity in the recent past that has arisen under business as usual conditions.
- ❖ Encompass anticipated business as usual altered activity in the project region on project or regionally similar lands including
    - o The projected regional extent of usage of the activities employed within the offset project.
    - o Emissions projections for any activities that would be replaced by the offset activities implemented within the project.

  Thus, for example, if a baseline is being formed for an afforestation project that converts agricultural lands to forest, then the baseline should contain projections of the business as usual afforestation rate and the GHG offset consequences there from as well as projections of the future emissions profile from the project agricultural lands that would be afforested if they remained in agricultural use.
- ❖ Omit coverage of regional activities that are not affected by project activity. Thus in developing a project baseline for a regional afforestation project one does not need baseline projections of local industrial emissions provided that the industrial activity and resultant emissions are not affected by project activities.
- ❖ Be established at least for the time period of anticipated project activity and/or for the length of the contract at hand.
- ❖ Be extended into the future beyond the contract duration to cover periods where major post contract or post activity changes are expected in emission reductions or emissions.
- ❖ Involve an apriori decision and possible contract negotiation as to whether the baseline will be revised at set periods of time. Some projects may persist over long periods but in such a context baseline setting may involve a high degree of uncertainty. Therefore, one possibility is to revise the baseline every set number of years, as conditions evolve. For example in some preliminary rulemaking activities revisable baseline periods of 3, 5, or 10 years have been proposed (Agriculture and Forestry GHG Reporting Workshops, 2003).
- ❖ Potentially reflect that greater efforts are needed to achieve adoption of the practices promoted under the project even though some adoption has already been observed because of regional heterogeneity i.e. that project activities would not have occurred under business as usual on the quality of the lands covered by the project.

A static projection sets the baseline at a fixed quantity of GHG offsets/emissions for the entire time period, whereas a dynamic projection allows the GHG offsets and emissions to vary over time as technical, biological, economic, and other factors evolve. A static baseline may make sense when dealing with mature technologies or when the timing of changes is too difficult to predict with any accuracy. However, the underlying processes in land use, land use change and forestry (LULUCF) projects, especially the forestry ones, are inherently dynamic over time and will not likely be well-represented by static projections. Either a dynamic baseline (if the temporal scale is long) or frequently revised static baselines might be warranted for LULUCF projects.

The decision on temporal, geographic and project specific extent of baseline coverage involves economic considerations, balancing the benefits of additional specificity against the costs. The more specifically the baseline is tailored to project conditions, the more accurate the baseline. However, the more tailored the baseline, the more cost involved in baseline construction and the more a project would cost. One way to economize on development costs is to use secondary guidelines such as

- Emission rates from the Intergovernmental Panel on Climate Change *Good Practice Guidelines*.
- State, county or regional level land-use changes as observed in the USDA National Agricultural statistics Service, Agricultural Census or the Natural Resources Inventory.
- Assumptions used in related and already accepted projects.

Project conditions may suggest that the secondary guidelines are not relevant for elements of the project in question. A hybrid of the project-specific and secondary guideline approaches might employ baseline parameters that are estimated for project categories, but involve localized work on key elements suggested by the characteristics and relative offset contributions of activities within a project. For example, if 90% of the offsets within a project come from agricultural tillage conversions then it may be worth developing project specific data on offset rates from localized tillage changes and anticipated future adoption of tillage practices.

4.1.2.1 Baselines can also involve emissions growth

Baselines are often viewed as items that, to the extent they contain business as usual adoption of the practices used in project, imply a reduction in the ratio of creditable to potential offsets generated by the project. On the other hand, it is possible that the baseline might reflect increasing emissions. For example, in a number of United States regions there is a recently observed expansion of rice acreage with land conversions from conventional crops or other land. This may imply a future scenario of increasing emissions of methane and other GHGs. Similarly, in a number of tropical areas there is an observed rate of tropical deforestation that when projected implies an increasing GHG emissions trend. In either case, a project that reverses these trends may not only obtain gains from project activity but also a reversal of the increasing emission trends. This could lead to a negative additionality discount. One does need to be careful under such circumstances to not include negative increments in the offsets (increasing emissions) if those in project area would need to obtain greenhouse gas credits to allow those emissions to occur.

4.1.2.2 Baselines, additionality and currently profitable practices

One baseline establishment issue involves the handling of currently profitable, but not employed practices. In particular, if within the project region the practices used by a proposed project are significantly more profitable than current land uses, then one might conclude that these opportunities should be adopted under current market conditions without need for GHG incentives. In this regard, it is commonly argued that such practices should be included within the business as usual baseline as opposed to being truly additional alternatives.

On the other hand, one needs to ensure that comprehensive cost accounting has been done including broader cost categories such as transactions costs, information costs, and producer incentives to overcome any increased risk and other factors. If this is not the case, then one should revise the cost estimates for practice adoption and this and enhanced cost consideration may mean the practice not more profitable and is truly additional. One could take the philosophical stance that since these practices are not currently being employed, that there are omitted cost factors, and therefore the project would have current benefits that are zero or negative and thus would not appear in the baseline.

4.2 Empirical specification of baselines and additionality discounts

The baseline formation process can range from arguments that everything is additional even including past practices through to cases where some proportion of project activity is projected to be adopted in the business as usual baseline. Regardless of the baseline formation stance, the basic additionality calculation is

$$\text{ProportionAdditional} = \frac{\text{WithProjectOffsets} - \text{BaselineOffsets}}{\text{WithProjectOffsets}}$$

In this calculation the baseline offsets data should only include offsets that would be displaced by the project as discussed above. This concept can accommodate all of the above baseline arguments allowing among other cases

- 100% additionality when the baseline does not change,
- Additionality in excess of 100% of the potential project offsets when the project yields positive offsets and the baseline shows increasing emissions (negative offsets).
- Positive partial additionality when the baseline and the project both show rising offsets.

Use of such an approach requires baseline projection. Now we turn attention to analytical methods of forming a baseline and then later address the exact computation of the additional quantity and then the accompanying additionality discount.

4.3 Alternatives for projection of a practice baseline construction

First, let us address construction of a baseline projecting practice usage (not an emissions baseline) on project lands. There are a number of alternatives for construction of such a baseline. These can be broadly categorized roughly following the IPCC into

- Simple logical, deductive approaches based on regional information.
- Statistical extrapolative approaches based on historical observations and possibly current and projected data.
- Simulation approaches based on models that depict activity in the affected region without the project.

Each will be discussed below.

4.3.1 Simple logical deductive basis

The simplest baseline approach involves construction of a logical, deductive baseline that is not based on modeling. This type of approach has been recommended in proposed rules as reviewed by the IPCC or in the rules suggested by the World Resources Institute. Such approaches are probably limited to small scale projects in specific areas and contexts but are likely inevitable as otherwise baseline efforts may represent a serious barrier to small-scale projects or initiatives in poorer countries (Bass *et al.*, 2000). More extensive methods are likely to be required for larger efforts. However, the more extensive methods require large amounts of data and may still be poor predictors of local changes.

The IPCC (2000) argues that deductive additionality criteria may be difficult to evaluate objectively on a project-by-project basis based on the evidence in Carter, 1997a and are thus at risk of being rejected.

4.3.1.1 Logical deductive Arguments for no change baseline

A number of proposed additionality tests have arisen over time in the international processes regarding offset eligibility rulemaking and are reviewed within the IPCC (2000) Land Use, Land Use Change and Forestry report or are suggested in the World Resources Institute proposed rules. Such tests when satisfied would permit project developers to assert that the baseline does not contain future expected adoption of the project employed practices. In turn, all offsets generated by the practices employed in the project would be additional. The fundamental tests as named in the IPCC (2000) report are based on financial, technological and or institutional matters. There is also one additional test that is related to this class that can be called the voluntary activity test.

4.3.1.1.1 Financial test

A financially based assertion that supports the deduction that the project practice is not in the future baseline is the statement that the project practices are financially unattractive. Such a statement asserts that the returns from the proposed practice are now and will continue to be inferior to those generated by existing practices and this dominance can only be reversed by GHG payments. Satisfaction of the test involves several pieces of evidence.

- ❖ One must develop revenue, cost and net profit data on the proposed and existing practices that shows net profits from the proposed practices are less than those for the existing practices.
- ❖ One must develop an argument that the financial returns will remain smaller over the project life.
- ❖ One should develop data that indicate the practice is not now being employed on lands that are essentially homogeneous to the lands covered by the project.

For example, in considering an afforestation project on agricultural lands one would want to show that

- ❖ Net returns to afforested practice are currently inferior to the net returns if the land continues in its current agricultural use.
- ❖ The relative inferiority of afforestation net returns is projected to continue.
- ❖ Similar existing lands are not being afforested.

Under such circumstances the baseline for change in practices is zero.

4.3.1.1.2   Project induced evolved technology test

When the above financial test is not passed one may assert a no change baseline exists if one can assert that the project critically relies on either

- ❖ Development of new technology, or
- ❖ Removal of constraints stopping the adoption of project technology.

In both cases the argument must be made that the technology development or barrier removal would not have occurred in the absence of project activity. Such a test is discussed in Carter, 1997b.

An example of such a case could involve an afforestation project which was nominally more profitable than current land uses but where the profitability gain depends on a new tree species that would not have been developed in the absence of project investments.

4.3.1.1.3   Project induced evolved institutional test

When the financial test is not passed one may argue relevancy of a no change baseline if one can reasonably assert that the project can critically relies on either

- ❖ The development of new institutional arrangements, or
- ❖ The removal of institutional or other regulatory constraints stopping the adoption of project technology.

In both cases, the argument must assert that the new institutional arrangements development and or constraint removal would not have occurred in the absence of project activity.

An example could involve a reduced tillage project which was nominally more profitable but that this profitability only exists because of project development of tillage based insurance that would not otherwise have come into existence.

4.3.1.1.4 Voluntary funding activity test

Another test which likely must be satisfied in addition to satisfaction of at least one of the above three tests is that project implementation is voluntary. In particular, one should argue that regulatory activity would not have inevitably caused project development.

A case where this test might cause a project to be judged to be not additional may involve agricultural offsets generated by improved agricultural manure management in a region where water quality regulations are forcing improved manure management under the business as usual case.

4.3.1.2 Other simple logical deductive baseline estimation

A logical, deductive baseline can also be formed using other approaches. Generally, such approaches do not use quantitative methods for predicting changes. For example, the IPCC (2000) land-use, land-use change and forestry report cites project justifications from project documents that say

- "Without intervention, the forest concerned will be sold for agricultural development" [Rio Bravo project (Programme for Belize, 1997a)]
- "Without intervention, loss of aboveground carbon stocks within the area will continue at approximately 1.5 percent per year" [Tipper *et al.*, 1998].

The IPCC report also states that "Variations of this approach have been used by most projects during the AIJ Pilot Phase [e.g., the NKCAP in Bolivia (Brown *et al.*, 2000); the RIL project in Sabah, Malaysia (Pinard and Putz, 1997); the PAP in Costa Rica (SGS, 1998)]".

To form such a deductive baseline one can

- Interview people in a region and develop through expert opinion based, consensus forming processes, a future projection of regional adoption of practices employed in a project.
- Do simple extrapolations from data.

This is the perhaps the most difficult baseline approach in terms of gaining external acceptance for several reasons

- While logical arguments are not necessarily less accurate in terms of predictive ability, it is difficult to document the veracity of the evidence upon which they are founded.
- Giving project developers the task of developing baselines also introduces the moral hazard that the developers may choose to report a baseline that maximizes their perceived benefits (Tipper and de Jong, 1998).

4.3.2 Statistical projection of future land and practice use

Baselines can be formed statistically by extrapolating historic data. Simplistically, suppose during recent years that 1% of the regional lands covered by or alike to those covered by a project have switched to the project practice. Under such circumstances one could extrapolate that in the baseline 1% of the land would switch during each future year under business as usual. Such extrapolative approaches can be developed using a Markov land-use projection or an econometric approach.

4.3.2.1 Multipractice Markovian based projections

The projection of land-use and land-use practices within a baseline construction exercise considers how land that begins in one usage or practice condition transitions into other conditions in the future. One method that has been used for making such projections system is the Markov model.

The Markov model assumes that prior land-use history does not matter and develops a probability that land currently employed under a particular land-use pattern or practice will switch to another pattern or practice at the end of a time period. The implementation of the Markov model requires that one construct a particular form of a table called a Markov transition matrix. That matrix (see the example in table 1) has rows specifying the initial land-use practice at the beginning of a time interval and columns specifying the land-use/practice at the end of the time period. In turn, the entries within the table are the proportional chances (or probability) that land that starts in the initial usage specified by the row will end in the usage specified by the column. The elements on the diagonal give the chance that lands starting in a particular use will remain in that use. The elements off the diagonal give the chance that land usage will change. The model must be established so that all possible land-uses are specified and thus the data in each row should sum up to one.

The Markov model has been used a number of times to simulate and explore land use change. For example, it was used by

- Bourne to describe and predict urban land use changes.
- Bell to investigate land use change patterns on San Juan Island, Washington.
- Muller and Middleton to examine land use changes in the Niagara area.
- Lubowski (2002a,b) and Lubowski, Plantinga and Stavins to construct a carbon sequestration supply function including both a baseline and to simulate the effects of carbon sequestration subsidies.

- Murray et al to construct a baseline for Mississippi bottom-line hardwoods from 1982 to 1997.

The data in Table 1, can be obtained by computing:

$$PR_{ij} = \frac{A_{ij}}{\sum_j A_{ij}}$$

where,

A_{ij} gives the amount of land that began the period in use *i* that ends the period in use *j*.

PR_{ij} gives the probability used in the Markov matrix that land beginning in use *i* will end up in use *j*.

These data do not give an annual transition rate as the data are drawn from say a five year interval. In order to find the annual transition rate, we need to develop one-step or one-year transition probability matrix from this multiple-year transition matrix. The n-step transition probability matrix is the result in Markovian theory of multiplying the single year transition probability matrix by itself N times

$$\mathbf{M}^{(n)} = \mathbf{M} \cdot \mathbf{M} \cdots \mathbf{M} = \mathbf{M}^n$$

where, $\mathbf{M}$ is the one-step transition probability matrix. The one-step transition probability matrix can be found by deriving the Nth root of the N-step Markov transition matrix. This can be done by solving an optimization problem for the elements of M as formulated in the GAMS program in Table 2.

$$Min \ \sum_i \sum_j dev_{ij}^+ + dev_{ij}^-$$

$$\sum_j M_{ij} = 1 \ for\, all\, i$$

$$M^5 = M * M * M * M * M$$

$$M_{ij}^5 + dev_{ij}^- - dev_{ij}^+ = Mobs_{ij} \ \ for\, all\, i\, and \ j$$

One can also do this by diagonalizing the matrix pre and post multiplying it by the matrices of its eigenvectors and then taking the 1/5th root of the eigenvalues as discussed in Lawler(1995) and as implemented in the spreadsheet addin Simetar (Richardson, Schumann and Feldman, 2004)

Once the Markov matrix has been estimated than one can form a baseline for future land use and practice use simply by computing the projected land-use/practice in year N as Markov matrix multiplied by itself N times in turn times the initial land-use

$L_0 = L_0$
$L_1 = M^* L_0$

$L_2 = M*M* L_0$

…

$L_N = M*M*…*M L_0 = M L_{N-1}$

Where L_i is the land use in year i

L_0 is initial land use

M is the annual Markov transition matrix

The Markov model is attractive because it can be used easily to predict future land use change. However,

- Model applicability may be limited because practice and land use data may not be available at the needed level (Murray et al 2003).
- The transition probabilities are invariant to incentives, trends, amount of land in each use etc. The econometric approach in the next section overcomes some of these deficiencies.

4.3.2.2 Econometrically based baseline projection

Future activity as reported in the baseline will depend on evolving economic and market conditions (commonly called drivers) as well as characteristics of the land base. The Markovian approach extrapolates the future baseline as a function of a continuation of the historic rate of shift in land-use practices. As such the approach assumes that current drivers persist into the future.

One can choose not to make such an assumption and assume that the forward projection of practice adoption depends on the drivers such as relative profitability, population, inventory of suitable land in the region, interest rates, and many other factors. Such projections are commonly dealt with using econometric techniques.

The basic nature of the econometric approach to the construction of practice change forecasts differs depending on the situation that underlies a project. Namely, one can face

- The simple case where the project involves a single practice replacing single pre-project practice.
- A more complex case where the project involves multiple practices are evolving from multiple pre-practice practices.

In the former case one can do rather simple econometric modeling. In the latter case one needs to pursue simultaneous equation econometric modeling to forecast the parameters of the Markov matrix discussed above.

4.3.2.2.1 Single practice single source

When a project advocates use of a single practice and the lands for the practice only come from a single source (i.e. afforestation on existing croplands) then one can estimate an equation that forecasts of the quantity of land area shifting into the new project practice as it is affected over time by attributes of the practice, the economy and the land inventory. Such a case would occur when the project involves afforestation of potentially flooded bottom land croplands and that the cropland inventory is finite and will not be replenished. In particular, one can estimate some form of an equation that forecasts practice adoption using an equation like the following

$$PracticeAdoption = \frac{f(PracticeReturns, LandCharacteristics, OtherFactors)}{AvailableLand}$$

Where

PracticeAdoption	is the projected annual proportional adoption of project practices.
PracticeReturns	is the returns difference between the current practice and the proposed project practice.
LandCharacteristics	describes the characteristics of the inventory of convertible lands.
OtherFactors	include many other potential factors such as market prices, population levels etc.
AvailableLand	is the amount of land available in the region for practice adoption.

An important estimation consideration involves potential censorship of the dependent variable. In particular, the minimum value of the dependent variable is zero and the maximum value is one (censoring the values to between zero and one) violating the normal regression assumptions with regard to the error term. The distributional problems caused by such censorship can be corrected for using standard econometric estimation methods such as those known as the logit or probit regression models (see Greene 2000). Such an analysis was done by Murray et al in the case of a potential project involving conversion of frequently flooded bottom land croplands in Mississippi into hardwoods.

4.3.2.2.2 Multiple practices from multiple sources

When a baseline is to be estimated for a project that involves

- A practice that can arise from one or more from one or more pre-existing land-use or practice conditions.
- More than one practice that can arise from one previous land-use conditions
- More than one practice arising from more than one current land-use.

then an econometric approach employing a Markov based land use share model is used. Land use share models have been widely used for various purposes in the past by, for example, Lichtenberg; Stavins and Jaffe; Wu and Segerson; Hardie and Parks; Miller and Plantinga(1997); Ahn, Plantinga and Alig; and Plantinga and Wu.

The key hypothesis behind the land use share model is that land use patterns are determined by relative rents, economic conditions and other land characteristics such as location and soil fertility (Miller and Plantinga). The most common approach is to specify the Markovian transition probabilities as a function of explanatory variables that include land rents from alternative uses, relevant policy variables, and land quality measures.

Lubowski develops both the theory and associated estimation procedures for the nested logit formulation of the Markovian transition probabilities in a sequestration setting. Miller and Plantinga (2003) develop an extended version of that model.

4.3.2.3 Data sources for land-use transitions

A number of datasets contain observations of how practices are distributed across the landscape over time. In particular, the

- USDA National Resources Inventory (http://www.nrcs.usda.gov/technical/NRI/) contains data that includes periodic data on land use/land cover, crop history, and conservation practices among other items for 800,000 sample points. Each point is designed to represent a larger land area and thus the data statistically represent land and natural resource conditions in larger areas. Coverage is for the 48 conterminous United States, Hawaii, Puerto Rico and the U.S. Virgin Islands. Data are unavailable for 1982, 1987, 1992, 1997 and 2001. Today the NRI is in transition to become an annual data set.
- USDA agricultural census data (http://www.nass.usda.gov/census/) contains county level data collected on a five-year interval mostly since 1974 with some data extending back to 1969. Data for 2002 is just emerging. The data give county level incidence of farm size, livestock numbers, crop acreage by irrigation status and a number of other characteristics.
- Forest Inventory and Analysis data (http://fia.fs.fed.us/). These data chronicle forest extent, cover, growth, mortality, removals, and overall health where the data collection proceeds continuously and repeated observations are available on a 5 to 10 year basis. The readily accessible data are mostly at the state and county level due to confidentiality requirements, but more disaggregate data requests can be made through http://fia.fs.fed.us/SpatialDataServiceCenter.htm. The data cover all forest land in the lower 48 States plus Alaska, Hawaii, and all of the territories and possessions of the US over all public and private forest land including reserved areas, wilderness, National Parks, defense installations, and National Forests and are derived from roughly 6000 hectare land units.
- Conservation tillage practice use data as developed by the Conservation Technology Information Center http://www.ctic.purdue.edu/CTIC/CRM.html which give county level usage of tillage practices on an annual basis by crop (note there is no data on practices by acre so the data do not show whether an acre stays in a practice continuously).
- The USGS National Land Cover Mapping http://edc.usgs.gov/geodata/ data contains national land cover coverage dividing use into 21 classes at the 30 square meter level derived from LandSat Thematic Mapper satellite imagery for 1992 and 1999. The 1999 data are not totally complete with USGS planning to complete the classification of these data by 2004.

4.3.3 Deriving a baseline from a simulation model

Another baseline projection alternative is to employ a simulation model to project what would happen in the absence of the project. This is an option that might be employed on when data on the practices used in the project are not available or when so much is expected to change in the future that one is willing to allow use of a more complex model to simulate what would happen. The simulation presumably would depict underlying economic, environmental, and institutional considerations. Several types of simulation models are relevant

- *Spatial* land-use change models that predict the future practice baseline taking into consideration factors such as proximity of towns, roads, and agricultural frontiers; population growth; food requirements; and the productivity of local agricultural technology [e.g., LUCS model (Faeth *et al.*, 1994); Ludeke, 1990; Jepma, 1995). This approach is being used in The Nature Conservancy's project in Guaraqueçaba, Brazil (Brown *et al.*, 1999a,b).
- *Dynamic sectoral* models that forecast what would happen over the next 10 years given the assumed internal market conditions. For example, there are models of the US Agriculture and forestry sectors (McCarl and Schneider or Adams et al) and the world forestry economy (Sohngen and Sedjo).
- *Regional project* models that forecast future land use at the project scale.

4.4 Layering in GHG offsets

Once the baseline has been formed in terms of practices then it must be transformed to a baseline in terms of net GHG emissions. This involves calculating the future trajectory of net GHG emissions when the practices that are forecast to occur in the baseline are implemented or continued in the future. This will include computation of the difference between emissions and sequestration under continuation of the current practices plus adjustments when and if some of the practices proposed within project are potentially adopted under business as usual. Procedures for calculating these GHG offsets appear elsewhere in this manual and are not discussed further in this section. Rather from here it is assumed that this has been done.

4.5 Development of additionality discount

Now let us develop an additionality discount formula. To start we return to our general discount formula where we equate the costs per unit

$$\text{CurrentCostPerOffsetTon}_{\text{perfect}} = \text{CurrentCostPerOffsetTon}_{\text{other}}$$

Under constant carbon prices and contract prices we get

$$\text{OffsetPrice}_0 = \frac{\sum_{t=0}^{T} (OffsetPrice_0 * (1 - AdditionalityDiscount) * QuanOffset_t + OtherCost_t) / (1 + Disc)^t}{\sum_{t=0}^{T} ClaimQuanOffset_t / (1 + Disc)^t}$$

Now let us particularize this to an additionality only case. First, assume that the maintenance costs equal zero. Also suppose that only part of the offsets generated are additional and thus the denominator needs to reflect the total quantity of claimable offsets generated times some additionality factor. In such a case given with project and baseline estimates the proportion of additional offsets in year t is given by the formula

$$\text{ProportionAdditional}_t = \frac{\text{WithProjectOffsets}_t - \text{BaselineOffsets}_t}{\text{WithProjectOffsets}_t}$$

which, in turn, can be included in our above formula to yield

$$\text{OffsetPrice}_0 = \frac{\sum_{t=0}^{T} (OffsetPrice_0 * (1 - AdditionalityDiscount) * QuanOffset_t\ ) / (1 + Disc)^t}{\sum_{t=0}^{T} QuanOffset_t * ProportionAdditional_t / (1 + Disc)^t}$$

If we assume the proportion of additional offsets does not vary over time, then this can be solved to yield

$$\text{AdditionalityDiscount} = 1 - \text{ProportionAdditional}$$

On the other hand, if the proportion of the offsets that are additional varies across the years, then the discount becomes

$$\text{AdditionalityDiscount} = 1 - \frac{\sum_{t=0}^{T} QuanOffset_t * ProportionAdditional_t / (1 + Disc)^t}{\sum_{t=0}^{T} QuanOffset_t\ / (1 + Disc)^t}$$

Finally, if we factor in varying contract and offset prices we get

$$\text{AdditionalityDiscount} = 1 - \frac{\sum_{t=0}^{T} CP_t / (1 + Disc)^t}{\sum_{t=0}^{T} EP_t\ / (1 + Disc)^t} * \frac{\sum_{t=0}^{T} EP_t * QuanOffset_t * ProportionAdditional_t / (1 + Disc)^t}{\sum_{t=0}^{T} CP_t * QuanOffset_t\ / (1 + Disc)^t}$$

4.6 Applications

Now let us compute the additionality discount over a number of cases.

4.6.1 No change baseline

The first and simplest application is one where the baseline exhibits none of the project practices being adopted and that the diversion of project lands does not have any other GHG implications other than those estimated under the with project case. Under such circumstances the baseline contains all zeros and the additionality discount is zero.

4.6.2 Constant baseline adoption

The next case is one where the baseline exhibits business as usual adoption of a proportion of the activity underneath the project. For example, suppose the project involves conversion of lands to a practice that creates one ton of GHG offsets per acre, but under business as usual 20% of the project activity would have occurred in the absence of the project. This then would exhibit a baseline that would increase GHG offsets by 0.2 tons per acre. In turn the resultant additionality discount is 20%.

4.6.3 Baseline and project evolution

Greenhouse gas offsets may change over time causing either a time dependent additionality discount or one that can be averaged via the above formulas into an average discount computed over the life of the project. Consider a case where a project is implemented which creates 1 ton of offsets per acre and that these offsets increase by 1% per year from there on. In addition, suppose that under business as usual 20% of the project activity would have occurred but that these offsets increase at a rate of either 1% or 2% per year. Under the 1% baseline offset increase rate the additionality discount would be 20% while under the 2% increase rate the additionality discount is 27.2%.

4.6.4 Baseline with multiple Changing Practices

Suppose we have a baseline which has multiple practices in it. Kim (2004) develops data on such a project that involves discontinuing rice production in favor of trees. His data which is drawn from the USDA Natural Resources Inventory suggests the following Markov transition matrix.

	Rice	Other crops	Grasslands	Trees
Rice	0.941	0.035	0.024	0
Other Crops	0	0.976	0.024	0
Grasslands	0	0	1	0
Trees	0	0	0	1

This matrix indicates that under business as usual 94.1% of the land found in rice at the beginning of a year remains in rice next year but that 3.5% switches to other crops and 2.4% to grasslands. In addition 97.6% of the land beginning in other crops remains in other crops in the following year but 2.4% of it moves out to grasslands. All of the land in grasslands remains in grasslands. Similarly all of the tree land remains in trees.

Kim also derives offset rates that indicate a conversion from rice to other crops yields approximately 1 ton of offsets per year while conversion from rice to pasture yields 1.5 tons per acre and rice to trees to yields 3 tons per acre. These offsets are composed of contributions from reductions in rice methane production, reductions in emissions based on needed tillage or water pumping operations, reductions in nitrous oxide arising from fertilizer application and increases in sequestration caused by the new land uses.

In turn, we can form a baseline by extrapolating the land use history. Such an extrapolation shows for example if we start off with 1 acre in rice that after 1 year we expect 94% of the land to remain in rice but other acres to appear in other crops and grasslands. Extrapolating this for 20 years 29.6% of the initial acreage would remain in rice, 31.8% would be found in trees and 38.4% would be in grasslands

Finally, assuming that all of the land was converted to trees one gets a with project potential offset rate of 3 tons per acre but a baseline offset that initially offsets zero tons but rises to an offset of 0.9 tons per acre after 20 years and on to 1.45 tons per acre after 100 years. The resultant additionality discount is 25.67%.

4.7 Spreadsheet implementation

The spreadsheet implementation of the above formula appears on the additionality worksheet of the file eddiscount.xls. Let us discuss the sheet in terms of inputs, outputs and calculations. We will also discuss the location of the data for the above illustrations and the calculation of the baseline for the Markov case.

4.7.1 Inputs

A screen shot of the upper left-hand portion of the additionality worksheet appears below

	A	B	C	D
1	**Basic Data**			
2	Discount/Interest Rate			4.00%
3	Contract price escalation rate			0.00%
4	Offset price escalation rate			0.00%
5	Carbon Price			30

On this worksheet we enter the discount rate, contract price escalation rate, and offset price escalation rate and base program price in the D column rows 2- 5. We also enter data on the project by year further down in the worksheet with the data for the with project results appearing in column B rows 25-125 for a 100 year project and the data on the baseline appearing in column C rows 25-125.

	A	B	C	D
19		**---- Annual Data on Project ----**		
20				
21				
22		Offset in	Baseline	
23		Category		
24	**Year**	Sequest 1		
25	0	3	0	
26	1	3	0.071	
27	2	3	0.138231	
28	3	3	0.201905	
29	4	3	0.262223	
30	5	3	0.319372	
31	6	3	0.373531	
32	7	3	0.424866	
33	8	3	0.473536	
34	9	3	0.519688	
35	10	3	0.563463	

4.7.2 Outputs

Two types of output appear in the worksheet as portrayed in the screen shot below

	A	B	C	D	E	F	G	H
1	**Basic Data**					**Results without discount**		
2	Discount/Interest Rate			4.00%		NPV Cost		2295.45
3	Contract price escalation rate			0.00%		NPV Carbon EQ		56.87382
4	Offset price escalation rate			0.00%		Present cost/ton		40.3604
5	Carbon Price			30				
6						**Results with discount**		
7	**Discount calculation**					NPV Cost		1706.215
8	**K**		1			NPV Carbon EQ		56.87382
9	Discount Numerator1		56.87382			Present cost/ton		30
10	Disount Numerator 2		56.87382					
11	Discount Denominator		76.515					
12	**Additionality Discount**		**25.67%**					
13	**Price Percent**		**74.33%**					
14								

The basic results of the additionality discount formula evaluation appear in column C rows 12 and 13 with the quantitative magnitude of the discount appearing in the cells C12 and C13. Additional results appear in the F, G and H columns with the present cost in the absence of discounting appearing in cell H4 and the present cost with discounting present appearing in cell H9.

4.7.3 Calculations

The basic calculations in the formula appear in two parts. The year by year calculations appear in columns E-O in rows 25-125. The summary evaluations then are in the upper left hand corner of the worksheet. A screenshot of the year by year calculations appears below.

	E	F	G	H	I	J	K	L	M	N	O	P
20				Discountec	Discounted							
21		Contract	Offset	Contract	Offset						Claimable	
22	Money	Price	Price	Price	Price				Payment	Payment	Current	
23	Discount	Multiplier	Multiplier	Multiplier	Multiplier	Proportion	Discount	Discount	without	with	Offset	
24	Factor	Factor	Factor	Factor	Factor	Additional	Numerator	Denominat	Discount	Discount	Eq	
25	1	1	1	1	1	100.0%	3	3	90	66.89726	3	
26	0.961538	1	1	0.961538	0.961538	97.6%	2.816346	2.884615	86.53846	64.32429	2.816346	
27	0.924556	1	1	0.924556	0.924556	95.4%	2.645866	2.773669	83.21006	61.85028	2.645866	
28	0.888996	1	1	0.888996	0.888996	93.3%	2.487496	2.666989	80.00967	59.47142	2.487496	
29	0.854804	1	1	0.854804	0.854804	91.3%	2.340263	2.564413	76.93238	57.18406	2.340263	
30	0.821927	1	1	0.821927	0.821927	89.4%	2.203281	2.465781	73.97344	54.98467	2.203281	
31	0.790315	1	1	0.790315	0.790315	87.5%	2.075737	2.370944	71.12831	52.86988	2.075737	
32	0.759918	1	1	0.759918	0.759918	85.8%	1.95689	2.279753	68.3926	50.83642	1.95689	
33	0.73069	1	1	0.73069	0.73069	84.2%	1.846063	2.192071	65.76212	48.88117	1.846063	
34	0.702587	1	1	0.702587	0.702587	82.7%	1.742634	2.10776	63.23281	47.00113	1.742634	
35	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	

These calculations are done for years 0-100 . The data in

- Column E gives an evaluation of the current value of a dollar received in year t ($1/(1+Disc)^t$)
- Column F gives an evaluation of the escalation in the contract price (CP_t) in year t
- Column G gives an evaluation of the escalation in the offset price (EP_t) in year t
- Column H gives an evaluation of the current value of receipt of the contract price in year t ($CP_t/(1+Disc)^t$)
- Column I gives an evaluation of the current value of receipt of the offset price in year t ($EP_t/(1+Disc)^t$)
- Column J computes the proportion additional quantity in year t ($(\text{WithProjectOffsets}_t - \text{BaselineOffsets}_t)/\text{WithProjectOffsets}_t$)
- Column K computes the right hand part of the numerator term from the discount formula $(EP_t * QuanOffset_t * \text{Pr}\,oportionAdditional_t / (1+Disc)^t)$
- Column L computes the right hand part of the denominator term from the discount formula $(CP_t * QuanOffset_t \ / (1+Disc)^t)$
- Column M computes the present value of the amount paid for an offset at the price in the absence of an additionality discount
- Column N computes the present value of the amount paid for an offset at the price with an additionality discount
- Column O computes the present value of the offset quantity

4.7.4 Output

In turn these data are used to compute the terms needed in the additionality discount formula. Here in the worksheet as portrayed in the screenshot below

- In cell C8 we compute the price escalation ration term adding up information from the annual columns H&I $\dfrac{\sum_{t=0}^{T} CP_t/(1+Disc)^t}{\sum_{t=0}^{T} EP_t \ /(1+Disc)^t}$

- In cell C10 we compute the numerator for the right hand part of the formula summing up information from the annual column K
  $\sum_{t=0}^{T} EP_t * QuanOffset_t * \Pr oportionAdditional_t / (1+Disc)$
- In cell C11 we compute the numerator for the right hand part of the formula adding information from the annual column L $\sum_{t=0}^{T} CP_t * QuanOffset_t \; / (1+Disc)$
- In cell C12 we compute the additionality discount using the results from C8-C11.
- In cell C13 we compute 1 minus the additionality discount.
- In cell H3 we compute the NPV of the amount paid if we do not apply an additionality discount summing the results from year by year calculations in column M.
- In cell H4 we compute the NPV of the offsets acquired summing the results from year by year calculations in column O.
- In cell H5 we compute the current cost per unit current offset in the absence of an additionality discount.
- In cell H7 we compute the NPV of the amount paid if we apply an additionality discount using the results from year by year calculations in column N.
- In cell H8 we compute the NPV of the offsets acquired using the results from year by year calculations in column O.
- In cell H9 we compute the current cost per unit current offset in the presence of an additionality discount.

	A	B	C	D	E	F	G	H
1	**Basic Data**					**Results without discount**		
2	Discount/Interest Rate			4.00%		NPV Cost		2295.45
3	Contract price escalation rate			0.00%		NPV Carbon EQ		56.87382
4	Offset price escalation rate			0.00%		Present cost/ton		40.3604
5	Carbon Price			30				
6						**Results with discount**		
7	**Discount calculation**					NPV Cost		1706.215
8	**K**		1			NPV Carbon EQ		56.87382
9						Present cost/ton		30
10	Disount Numerator		56.87382					
11	Discount Denominator		76.515					
12	**Additionality Discount**		**25.67%**					
13	**Price Percent**		**74.33%**					

4.7.5 Location of the alternative additionality cases

The data for the additionality discount cases outlined above appears in the spreadsheet in the columns R-AM generally starting in row 18.

4.7.6 Baseline with Markov matrix

The Markov model based calculation of the baseline for the Kim (2004) rice case merits explanation. As shown in the screenshot below these data are present in columns AH-AM in rows 11 and below. The Markov transition matrix is in the solid box just below. Following that in row 19 is the assumed original land allocation with all of the intial project area in rice land. Below that are the assumed offset rates. Finally in the dashed box there are the baseline computations.   Namely, in

- Row 25 columns AJ-AM, the initial land allocation appears.
- Row 26 columns AJ-AM, the land allocation in line 25 times the Markov matrix appears which gives projected land use in year 1.
- Row 27 then is the row 26 land allocation times the Markov matrix giving projected land use in year 2 and so on for all subsequent rows.
- The entries in column AI are the offsets arising under the land use in columns AJ-AM which are computed by multiplying the land allocation in the row for each year times the offset rates from row 20. The with project offset is assumed constant at the rate for conversion to trees.

	AH	AI	AJ	AK	AL	AM
11		Kim Baseline				
12			Rice	Other crop	Grassland:	Trees
13		Rice	0.941	0.035	0.024	0
14		Other crop	0	0.976	0.024	0
15		Grassland:	0	0	1	0
16		Trees	0	0	0	1
17						
18			Rice	Other crop	Grassland:	Trees
19	Initial land allocation		1	0	0	0
20	Offsets per acre		0	1	1.5	3
21						
22	with					
23	Project	Baseline				
24	Offset	Offfset	rice	crops	pasture	trees
25	3	0	1	0	0	0
26	3	0.071	0.941	0.035	0.024	0
27	3	0.138231	0.885481	0.067095	0.047424	0
28	3	0.201905	0.833238	0.096477	0.070286	0
29	3	0.262223	0.784077	0.123324	0.092599	0
30	3	0.319372	0.737816	0.147807	0.114377	0
31	3	0.373531	0.694285	0.170084	0.135632	0
32	3	0.424866	0.653322	0.190301	0.156376	0
33	3	0.473536	0.614776	0.208601	0.176623	0

4.8 Handling multiple offset categories

The additionality discount herein has been was applied to the project offset on a uniform basis. However, a project is likely to create different offsets with different additionality characteristics. As a consequence, one should not apply the same additionality discount to all of the offsets created by a project, but rather should separate the accounts into different classes with essentially identical characteristics. Subsequently one would calculate individual discounts then unify results from all the classes and their particular discounts in a total economic analysis within the project proposal and reporting documents.

4.9 Baseline updating

Baselines can be

- ❖ Fixed for the lifetime of the project
- ❖ Updated periodically
- ❖ Updated after unexpected events.

Baseline updating increases purchaser/project developer uncertainty and cost (UNCCCS, 1997) but would increase the certainty in the offsets involved. Unraveling changes observed after the implementation of the project from the impact of the project itself can be difficult. Discussion of methods for adjusting baselines and their implications appears in Michaelowa (1997, 1998, 1999) and Ellis and Bosi (1999).

4.10 Credibility, safety and baselines

Additionality was a key consideration in the recent deliberations by the IPCC CDM executive board/methods where many projects were rejected. In that process many projects were judged to not be additional. This indicates one need to present a convincing analysis indicating the project is additional. To guarantee acceptability, a well thought out baseline and set of arguments are needed. Furthermore, one is safest if a project can be shown to be 100% additional.

Policy makers could try to insure better baseline formation by conditioning a credit discount based on the quality of the baseline as argued in Chomitz (1998).

4.11 Summary

Baselines and additionality are key concepts in project formation. The basic position is that GHGE offset quantities should only be creditable when they are truly additional to what would have happened in the absence of a GHG program. To compute the additional amount one must form a without project baseline which projects the future path of projet area GHG offsets. Arguments can be made that project activities can be 100% additional or the concept of partial additionality can be pursued. Use of the partial additionality concept is important, otherwise many potential projects may be overlooked.

When partial additionality is present the project will receive a discounted price or not be able to sell all generated offsets, only the additional ones. A formula is developed above for additionality discount computation and examples are given of baseline computation.

Table 1 Example of Markov Transition Matrix of Land Use

		Land use at end of period				
		Crop	Forest	Pasture	Other	Row total
Land use at Beginning of period	Crop	P_{CC}	P_{CF}	P_{CP}	P_{CO}	1.0
	Forest	P_{FC}	P_{FF}	P_{FP}	P_{FO}	1.0
	Pasture	P_{PC}	P_{PF}	P_{PP}	P_{PO}	1.0
	Other	P_{OC}	P_{OF}	P_{OP}	P_{OO}	1.0

Note that P_{ij} is the probability that land that begins in use i is converted to land use j during the period of interest. Reading across a row this gives the probability that land in use i is converted to use j during the time period. Reading up or down a column shows where lands that are observed in a use at the end of the period began from.

Table 2 GAMS program to get Markovian annual matrix

```
set states /rice, crops,pasture,trees/;
alias(states,i,j,k);
table targettransition(states,states)
          rice crops pasture trees
rice       .7    .3
crops            .8    .1      .1
pasture                .9      .1
trees                  .05     .95;

variable sumart;
positive variables
  transition(states,states)       target transition matrix
  transitionsq(states,states)     square of target transition matrix
  transitionfour(states,states)   fourth power of transition matrix
    transitionfive(states,states) fifth power of transition matrix
    artdevplus(states,states)     positive deviation artificial
    artdevminus(states,states)    negative deviation artificial;
equations
    square(states,states) square of M matrix
    fourth(states,states) fourth power of M matrix
    fifth(states,states)  fifth puwer
    devs(states,states)   deviation
    equalone(states)      row sum=1
    obj;

square(i,j).
         transitionsq(i,j)=e=
               sum(k,transition(i,k)*transition(k,j));
fourth(i,j).
        transitionfour(i,j)=e=
               sum(k,transitionsq(i,k)*transitionsq(k,j));
fifth(i,j).
         transitionfive(i,j)
               =e=sum(k,transitionfour(i,k)*transition(k,j));
devs(i,j).
         transitionfive(i,j)-artdevplus(i,j)+artdevminus(i,j)=e=
         targettransition(i,j);
equalone(states). sum(k,transition(states,k))=e=1;
obj. sumart=e=sum((i,j),artdevplus(i,j)+artdevminus(i,j));

model markov /all/;
*    intiial guess
    transition.l(i,j)=diag(i,j)-(diag(i,j)-targettransition(i,j))/5;
    display transition.l;
solve markov using nlp minimizing sumart;
display transition.l,sumart.l;
```

5 Assessing Leakage

The effectiveness of project based offsets can be undermined if actions to alter GHG offsets in turn stimulate associated GHG emissions elsewhere (Barrett (1994), Stavins (1997)). Such a phenomenon is called **leakage**. When leakage is present the global reduction in net emissions under implementation of a project is less than the project direct level of potential offsets. Leakage largely occurs because of

- Projects stimulate alterations in commodities entering markets and market prices.
- Such changes in turn induce production alterations outside the project.
- Accompanying such external production alterations are emissions increases.

Leakage can manifest itself in a number of ways. Consider an example involving forest carbon sequestration. Suppose, in the name of carbon sequestration, timber harvest is reduced in a significant region in the United State Pacific Northwest. Such an action would reduce the amount of harvested timber entering the market. However, given less wood, consumers look for additional wood from other sources and prices rise. In turn, additional harvest in other regions replaces the reduced Pacific Northwest harvest with accompanying increases in GHGE. This example is not hypothetical, reductions in Pacific Northwest public lands harvest in the 1990s were matched by accelerated rates of harvest on Pacific Northwest private lands, as well as harvest on lands in Canada and in the Southern U.S. (See Wear and Murray (2001) and Murray, McCarl and Lee (2002) who treat this case deriving leakage estimates in the neighborhood of 85%).

Leakage is a phenomenon that arises principally because of partial coverage across the landscape of a GHG emissions regulatory program. If all regions are uniformly covered such that additional stimulated emissions count against the overall emission limit requiring offsets, then there would be no issue. On the other hand, if the GHGE regulatory scheme operates on a project basis without global coverage or if the GHGE regulatory system covers only part of the countries, then leakage does become a concern. Namely, when there are production regions outside the regulatory scheme and if regulatory actions push production into those regions stimulating emissions without accompanying offsets, then leakage is present.

Leakage has been discussed in the international discussions directed toward formulating GHGE regulatory schemes. For example, in the Kyoto Protocol while participating country GHGE accounting is treated on a national basis, leakage is discussed in a project context (under the section on the Clean Development Mechanism among other places).

Consideration of leakage implies that projects need to be evaluated under broad national and international accounting schemes so that both the direct and indirect implications of project implementation are examined including offsite stimulated leakage. Project evaluations need not only look myopically at the project, but also at major competitive regions. In such a context a leakage discount will be manifest in either

- Reduction of the quantity of potential offsets that can be credited and thus sold so that the creditable quantity reflects adjustments for external leakage.
- Reduction in the price per ton paid by the purchaser so it is multiplied by one minus a leakage discount factor. That leakage discount factor would reflect the external leakage.

5.1 Leakage in the literature

Leakage has been addressed in a number of different circumstances.

5.1.1 Forestry context,

In a forestry context, Lee, Kaiser and Alig (1992) examine U.S. tree planting programs and find that government subsidized tree planting programs lessen private tree planting. Alig et al. (1997) use a model of the U.S. forest and agricultural sectors and find that the GHG benefits of an afforestation program are largely offset by a corresponding conversion of other forestland to agriculture. Recent papers have addressed the issue either inferring the magnitude of leakage potential analytically (Chomitz 2002), synthesizing the studies addressing leakage or related phenomena (Schwarze et al. 2002), or qualitatively assessing leakage potential and assigning ad hoc values for the leakage deduction (Aukland et al. 2003; Geres and Michaelowa 2002). Murray, McCarl and Lee (2004) develop a formula to estimate the quantity of leakage and apply it estimating leakage rates and also examine leakage in a modeling context. Chomitz (2002) compares the potential from leakage from forestry projects to that from energy-sector projects and argues that the former are not systematically more prone to leakage than the latter (as some parties have argued they are).

5.1.2 Agricultural context

Leakage also occurs when pursuing agricultural projects. For example, if we convert cropland into grasslands in one region in the name of sequestration, that conversion would lower crop production and raise prices stimulating producers in other regions to increase crop production possibly developing croplands from grasslands, forest lands, or wetlands. Wu finds that under the United States conservation reserve program, that move crop lands into reserved categories consistent with carbon sequestration, that about 20% of the reserved acres were replaced by additional acreage moving into the cropland category, again a finding of leakage. Leakage findings have also appeared in the context of slippage rates estimated with respect to farm program land set asides. Hoag, Babcock, and Foster (1993) , Brooks, Aradhyula, and Johnson (1992) and Rygnestad and Fraser (1996) all found that acreage reductions were larger than total production reductions because of retirement of less productive lands in a heterogeneous landscape. Wu, Zilberman and Babcock (2001) show that such problems make cost benefit analysis of individual projects misleading and argue for more comprehensive treatment.

Leakage can occur internationally. Lee et al (2000, 2001) show in a modeling context that unilateral implementation of agricultural GHGE offsets leads to a decline in host country exports and an increase in international production.

5.1.3 Energy context

A number of studies have been done in the energy context finding leakage on the order of 10-20% (Oliveira-Martins, Burniaux, and Martin (1992); Manne and Rutherford (1994); Jacoby et al (1997); Smith (1998); Barker (1999); Bernstein, Montgomery, and Rutherford (1999); Anderson, and McKibbin (2000); and Babiker (2001)). Felder and Rutherford (1993) show that international leakage can arise in energy markets.

5.2 Defining a leakage discount

Now suppose we define the leakage discount. We do this again utilizing our general discount formula where we equate the costs per unit of offset

$$\text{CurrentCostPerOffsetTon}_{\text{perfect}} = \text{CurrentCostPerOffsetTon}_{\text{other}}$$

Under the assumptions that: (1) the prospect on the left-hand side is perfect exhibiting no leakage, permanence, additionality, or uncertainty issues; (2) the right hand side project only exhibits leakage; and (3) both GHG offset and contract prices are constant over time; we get

$$\text{OffsetPrice}_0 = \frac{\sum_{t=0}^{T}(OffsetPrice_0 * (1 - LeakageDiscount) * QuanOffset_t + OtherCost_t)/(1+Disc)^t}{\sum_{t=0}^{T} ClaimQuanOffset_t/(1+Disc)^t}$$

Now let us further particularize this to a leakage only case. First, let us assume that the other (maintenance) costs are zero. Second suppose that project activity simulates emissions (leakage) elsewhere and thus that only parts of the offsets are claimable in a global GHGE offset system. Consequently, the quantity in the denominator needs to reflect not only the quantity of potential offsets generated by the project, but also a leakage adjustment. In such a case, we can express the proportion of potential offsets that are creditable after adjustment for leakage in year t using the formula

$$\text{ProportionNotLeaking}_t = \frac{\text{ProjectOffsets}_t - \text{OffsetingLeakedEmissions}_t}{\text{ProjectOffsets}_t}$$

which, in turn, can be included in our above formula to yield

$$\text{OffsetPrice}_0 = \frac{\sum_{t=0}^{T}(OffsetPrice_0 * (1 - LeakageDiscount) * QuanOffset_t)/(1+Disc)^t}{\sum_{t=0}^{T} QuanOffset_t * ProportionNotLeaking_t/(1+Disc)^t}$$

Further, if we assume the proportion of leaking offsets does not vary over time this can be solved to yield

$$\text{LeakageDiscount} = 1 - \text{ProportionNotLeaking}$$

On the other hand, if the proportion of the offsets that leak varies across the years then the discount becomes

$$\text{LeakageDiscount} = 1 - \frac{\sum_{t=0}^{T} QuanOffset_t * ProportionNotLeaking_t \,/\, (1+Disc)^t}{\sum_{t=0}^{T} QuanOffset_t \,/\, (1+Disc)^t}$$

Finally if we factor in varying contract and offset prices we get

$$\text{LeakageDiscount} = 1 - \frac{\sum_{t=0}^{T} CP_t \,/\, (1+Disc)^t}{\sum_{t=0}^{T} EP_t \,/\, (1+Disc)^t} * \frac{\sum_{t=0}^{T} EP_t * QuanOffset_t * ProportionNotLeaking_t \,/\, (1+Disc)^t}{\sum_{t=0}^{T} CP_t * QuanOffset_t \,/\, (1+Disc)^t}$$

5.3 Estimating leakage rates

Leakage can occur almost anywhere worldwide and it is in general impossible to observe the leakage created by a project. Furthermore, there is the obvious problem that one may need the leakage estimate before implementing the project as opposed to afterward. As a response, a mixture of theoretical analytical approaches, empirical modeling techniques and adaptive approaches have been used in order to estimate the magnitude of leakage.

5.3.1 Theory based analytical estimation

Formulae estimating leakage rates have been developed based on the theoretical economic deductions by Murray, McCarl and Lee (2004) and Kim (2004). The Murray, McCarl and Lee approach is based on diverted production in the commodity markets. The Kim approach is based on the amount of land diverted. Both will be presented.

5.3.1.1 Leakage based on quantity produced

Murray, McCarl and Lee (2004) develop the following estimation formula for leakage

$$L = \frac{e * C_{out}}{[e - E * (1+\phi)]\, C_{proj}}$$

where

- L — provides an estimate of the leakage discount which is proportion of the potential offsets offset by leakage. This is derived so it equals the amount of emissions released through induced expansions in offsite emissions divided by the amount of potential offsets saved by the project.
- e — is the price elasticity of supply for off project producers.

E	is the price elasticity of demand for the consumption of the final commodity produced.
C_{out}	is the amount of GHG emissions produced per unit of increased commodity production outside the project area.
C_{proj}	is the amount of potential GHG offsets produced per unit of reduced commodity production in the project area.
ϕ	is a measure of relative market share and is the total quantity of the commodity produced by the project divided by the amount produced elsewhere.

5.3.1.1.1 Definition and calculation of formula parameters

The above equation contains a number of parameters. Below notes are given on estimating them.

5.3.1.1.1.1 Price elasticity of supply

The parameter e gives the price elasticity of supply which is the percentage change in quantity supplied of a commodity resulting when a one percent change is observed in the commodity price.

$$e = \frac{\frac{\Delta Q_c}{Q_c}}{\frac{\Delta P_c}{P_c}}$$

where

Q_c	is the quantity of a commodity supplied before the price change.
ΔQ_c	is the change in the quantity of the commodity supplied induced by a price change.
P_c	is the price of the commodity received by suppliers before the price change.
ΔP_c	is the price change producers receive for the commodity

Empirically this can be found by using historical data or the results of other studies. One can compute a so called arc elasticity given two observations with differing prices

$$e = \frac{\frac{Q_{c2} - Q_{c1}}{(Q_{c2} + Q_{c1})/2}}{\frac{P_{c2} - P_{c1}}{(P_{c2} + P_{c1})/2}}$$

where the subscripts 1 and 2 depict observations in two different time periods. It is important in such an exercise that the interval between the periods be long enough to allow full adjustments to the price. Such estimates should not come from a short duration interval where adjustments may be constrained by short run fixed stocks of equipment or other considerations.

One may also use an econometric approach which can be of various forms of rigor. Under such circumstances one would estimate the function

$$Q_c = f(P_c, O)$$

where O is other factors affecting the supply like input prices. In turn, one would estimate the elasticity using the formula

$$e = \frac{\partial Q_c}{\partial P_c} * \frac{P_c}{Q_c}$$

Murray, McCarl and Lee construct an estimate of e when they apply their leakage formula to a Pacific Northwest forestry preservation case. Their e estimate was a timber production weighted average of Wear and Murray's four regional elasticity estimates and equaled 0.46.

5.3.1.1.1.2 Price elasticity of demand

The term E in the equation gives the price elasticity of demand which is the percent change in quantity demanded of a commodity that occurs with a one percent change in the commodity price.

$$E = \frac{\frac{\Delta Q_c}{Q_c}}{\frac{\Delta P_c}{P_c}}$$

where

- Q_c is the quantity of a commodity demanded before the price change.
- ΔQ_c is the change in the quantity of a commodity demanded in association with a price change
- P_c is the price of the commodity paid by those who buy from all commodity suppliers before the price change.
- ΔP_c is the associated change in the price paid.

Empirically, this can be found by using historical data, the results of other studies or econometrics. Most simplistically an arc elasticity can be computed as discussed in the section just above given two observations with differing prices. Again it is important that the period between the two observations be long enough to allow full adjustments to the price and not come from a short period where the adjustments may be highly constrained by short run considerations.

One may also use an econometric approach which can be of various forms of rigor. Under such circumstances one would estimate the function

$$\mathrm{Q_c} = f(P_c, O)$$

where O is other factors affecting the demand like the prices of other goods. In turn, one would estimate the elasticity using the formula:

$$E = \frac{\partial \mathrm{Q_c}}{\partial P_c} * \frac{P_c}{\mathrm{Q_c}}$$

Kim (2004) finds this demand elasticity for a project that reduces rice acreage using an econometric approach. Namely he regressed total US rice consumption (Q_c) on rice price (P_c) , the consumer Price Index (CPI), and total rice expenditures (EXP) using a log linear functional form. He also employed a Cochrane-Orcutt procedure to correct for serial correlation and imposed a restriction that the function is homogeneous of degree zero in prices and nominal income (Attfield). His results were

$$\begin{array}{lllll} \mathrm{Ln}\, Q_c = & 0.9064 & -\,0.9139\ \mathrm{Ln}\, P_c & -\,0.1672\ \mathrm{Ln}\, CPI & +\,1.0811\ \mathrm{Ln}\, EXP \\ & (4.210) & (-13.610) & (-4.788) & (20.558) \end{array}$$

R-Square = 0.924 DW = 2.00

where

- Ln is the symbol for the natural logarithm.
- The numbers in parentheses are t statistics.
- R-Square is a goodness of fit indicator.
- DW is the Durbin Watson statistic (Harvey, 1990) which tests for the presence of serial correlation.

From above results, the demand elasticity (E) is –0.9139.

Users should be careful to estimate the demand elasticity for the total market, not a localized or country market when goods are exported.

5.3.1.1.1.3 Relative market share

The relative market share parameter ϕ indicates how important the production under the project is relative to the total market for the commodity. Namely, if the total production in the market is S and the production by the project would be S_{proj} then

$$\phi = \frac{S_{proj}}{S}$$

which gives the proportion that production in the project region is of production outside the region. Again production outside the region should be that in the total market minus that in the project area.

5.3.1.1.1.4 Offsets per unit of product

The final two parameters give the rate of GHG offsets produced per unit of commodity produced in and outside of the project region. Namely,

C_{out} is the amount of offsets produced per unit of increased commodity production outside the project area.

C_{proj} is the amount of offsets produced per unit of reduced commodity production in the project area.

Since these appear as a ratio in the formula ie C_{out}/C_{proj}, then the important parameter is the ratio of offsets produced outside the project area C_{out} to the production in the project area C_{proj}. Murray, McCarl and Lee treat these as equal in their empirical work.

5.3.1.1.2 Leakage sensitivity

The table below shows explorations of leakage sensitivity based off of the Murray, McCarl and Lee data where the item changed is bolded and in a larger font. The results show leakage decreases as

- Supply becomes more inelastic (e becomes smaller)
- Demand becomes more elastic (E becomes larger in absolute value)
- Market share in the project increases (ϕ becomes larger).
- Per unit offsets relative to commodity production for the project area (C_{proj}) become smaller relative to per unit induced emissions outside the project area (C_{out}).

	Base	-------------- Variants			--------------------
Supply Elasticity e	0.46	**0.1**	0.46	0.46	0.46
Demand Elasticity E	-0.06	-0.06	**-1**	-0.06	-0.06
Market share (phi)	0.045	0.045	0.045	**0.050**	0.045
Offset in project (Cproj)	22.22	22.22	22.22	22.22	22.22
Offset outside project (Cout)	22.22	22.22	22.22	22.22	**44.44**
Time independent leakage	88.00%	61.46%	30.56%	87.95%	44.00%

5.3.1.2 Leakage based on land diverted

Kim (2004) set up a leakage estimation formula based on the amount of acreage diverted by a project. That formula follows

$$\text{Leak} = \frac{\text{e } E\text{L}_{\text{proj}}}{[\text{e - E} * (1 + \text{El}_{\text{out}}\phi)]} \frac{LCR_{out}}{LCR_{proj}}$$

where

e, E, and ϕ are as defined for the commodity dependent Murray, McCarl and Lee formula presented above.

EL_{proj} is the elasticity of commodity production with respect to changes in project land use. Namely, it is the percentage decrease in commodity production per one percent increase in project land used for the GHG offset project.

EL_{out} is the elasticity of commodity production with respect to changes in offsite land use. Namely, it is the percentage increase in commodity production per one percent increase in offsite land used for commodity production.

LCR_{out} is the GHG emission increase per acre that arises when additional acres are used to produce the commodity outside the project area.

LCR_{proj} is the GHG potential offset per acre in the project region created by developing the project.

5.3.1.2.1 Estimating needed parameters

The above equation contains a number of parameters. Below notes are given on estimating those. However, note we will not cover e, E, and ϕ as estimation procedures for them are given in the Murray, McCarl and Lee commodity related leakage formula section above.

5.3.1.2.1.1 Elasticity of commodity production when land changes

The parameter EL_{proj} and EL_{out} indicates how much commodity production will change when land use is altered by the use of land on and off the project. Namely, EL_{proj} is the percentage reduction in commodity production per one percent increase in the amount of land used for the project.

$$EL_{\ln d} = \frac{\frac{\Delta Q_c}{Q_c}}{\frac{\Delta Q_L}{Q_L}}$$

where

Q_c is the quantity of a commodity produced before the land use change.

ΔQ_c is the change in the quantity of a commodity produced in association with the land use change.

Q_L is the quantity of land used for commodity production before the land use change.

ΔQ_L is the change in the quantity of land used for the project.

Similarly, EL_{out} is the percentage increase in commodity production per one percent increase in the amount of land used for commodity production off project.

Empirically, these items can be found by using historical data, the results of other studies or econometric procedures. Most simplistically, an arc elasticity can be computed, as discussed in the section above, given two observations with differing land uses and commodity production levels. Again it is important that the period between the two observations be long enough to allow full adjustments to the land use change and not be highly constrained by short run considerations.

One may also use an econometric approach which can be of various forms of rigor. Under such circumstances one would estimate the function

$$\mathrm{Q_c} = f\,(Q_{\mathrm{L}}\,, O)$$

where Q_L is the quantity of land used and O identifies other factors affecting production like the prices of inputs and outputs. In turn, one would estimate the elasticity using the following formula.

$$EL = \frac{\partial \mathrm{Q_c}}{\partial Q_{\mathrm{L}}} * \frac{Q_{\mathrm{L}}}{\mathrm{Q_c}}$$

Kim (2004) finds this production elasticity in a rice production context using an econometric approach. Namely, he estimates a regression for U.S. national production relating production to harvested acreage using data from 1981 – 1999 including a trend variable. He also uses a Cochrane-Orcutt procedure to correct for serial correlation and assumes that the input elasticity is constant over time and regions. His results are as follows (Numbers in parentheses are t-values):

$$\begin{aligned} &\mathrm{Ln}\ Q^S = -2.7054 + 0.9003\ \mathrm{Ln}\ L - 0.0099\,\mathit{Trend} \\ &\qquad\quad (-3.270)\quad (12.898)\qquad\quad (-2.737) \\ &\text{R-Square} = 0.924 \qquad \text{DW} = 1.92 \end{aligned}$$

where, Q^S is rice production, L is harvested acreage and Trend is year. From the above results, the production response elasticity with respect to changes in land is estimated as 0.9003. In other words, rice supply decreases by 0.9% when rice land decreases by 1%.

5.3.1.2.1.2 Land-based emission rates

One also needs estimates of LCR_{out} and LCR_{proj} which are the GHG offset rates per acre used for production of the commodity inside and outside the project region. Estimation inside the project region is the subject of coverage elsewhere in this manual. Estimation outside the project region should focus on acres that are likely to adjust if the project alters production of the commodity.

Kim (2004) addresses estimation of these parameters using the Markovian approach above for acreage in the U.S. outside of the project region. He computes the transition matrix for rice, other crops, pasture and forests computing the sources of acreage that moved into rice over recent times and then applies the offsets derived herein to compute the greenhouse gas emission rates.

5.3.1.2.2 How big is leakage

The table below contains cases that collectively reflect leakage sensitivity based on the Kim data. The bolded items in the larger fonts identify the items changed. The results show leakage decreases as

- Supply becomes more inelastic (e becomes smaller).
- Demand becomes more elastic (E becomes larger in absolute value).
- Commodity market share in the project increases (ϕ becomes larger).
- On project elasticity of land use response becomes smaller (EL_{proj}).
- Off project elasticity of land use response becomes larger (EL_{out}).
- Per acre on project offsets (LCR_{proj}) become larger relative to the per acre offsite emissions (LCR_{out}).

	------------------------------ Variants ------------------------------------						
Supply Elasticity e	0.376	**0.1**	0.376	0.376	0.376	0.376	0.376
Demand Elasticity E	-0.91	-0.91	**-1**	-0.91	-0.91	-0.91	-0.91
Commodity market share (phi)	0.081	0.081	0.081	**0.09**	0.081	0.081	0.081
Project elasticity of prod.	1.00	1.00	1.00	1.00	**0.70**	1.00	1.00
Offsite elasticity of prod.	1.00	1.00	1.00	1.00	1.00	**1.20**	1.00
Ratio Per acre offsets	1	1	1	1	1	1	**0.5**
Time independent leakage	27.6%	9.2%	25.8%	27.4%	19.3%	27.3%	13.8%

5.3.2 Modeling

A second approach to leakage rate estimation involves the use of modeling. Experiments have been done, for example, by Murray, McCarl and Lee where a sector wide model is employed and imposes project completion (a given fixed amount of preserved forest) then observes the difference between potential onsite project offset and the total change in greenhouse gas net emissions across the whole sector. In their analysis, they examined avoided deforestation. The leakage estimates they found appear in the table below.

Region	No Harvesting Allowed	Harvesting Allowed
Pacific Northwest—east side	8.9%	7.9%
Northeast	43.1%	41.4%
Lake states	92.2%	73.4%
Corn Belt	31.5%	–4.4%
South-Central	28.8%	21.3%

The advantage of examining leakage in a modeling rather than an analytic framework is that in such a more comprehensive framework

- Multiple markets are simultaneously considered.
- One can examine the dynamic aspects of leakage provided the model accommodates it.

For example, avoided deforestation will have implications not only for current harvest but also for harvesting in future periods. Similarly, afforestation certainly influences future harvest régimes. Neither phenomena is immediately accommodated in the analytical formulae above.

On the other hand, there are advantages to using the formulae. Namely, use of a comprehensive sector model

- Takes more time
- Requires model availability
- Requires a model that is comprehensive enough to meaningfully measure leakage (for example small regional models that are closed to external trade would not fully portray leakage).
- Must contain comprehensive greenhouse gas accounting or otherwise be recognized as being limited to providing commodity market only leakage implications as in Wear and Murray or in Lee et al (2000, 2001).

A number of different types of economic models can be used. This includes static models like

- An agricultural sector model that portrays production in a single year such as that used in Lee et al (2000,2001).
- Dynamic models such as FASOM as used by Murray, McCarl and Lee that are focused on either single or multiple sectors.
- General equilibrium models such as the energy related models used by Manne and Rutherford (1994).

5.3.3 Deduction of zero leakage

In addition to dealing with leakage utilizing formal modeling approaches one may argue that leakage is effectively zero under certain circumstances. The arguments for zero leakage differ between project types in particular depending upon whether

- Project implementation conceivably changes land use and in turn can influence commodity production.
- Project implementation precludes items from coming onto the marketplace like avoided deforestation.

Each will be discussed below.

5.3.4 Commodity markets

Leakage can be argued to be effectively zero when a project is implemented which does not affect commodity production. Aukand et al call this a project that is not "commercially oriented" meaning implementation does not effect commodity production. An example where such an argument might be made involves the recovery of methane emissions from intensive livestock manure lagoons. Such project is likely to have no effect on commodity (dairy) production.

A further qualification also needs to be entered, namely that the project alternative does not lower production costs. The reason for this can be illustrated by considering an example. In the 1980s and 1990s the State of Texas decided to subsidize water conserving irrigation practices lowering their cost and this resulted in an expansion of irrigated acreage. In turn, while a reduction in irrigation water use per acre was observed, the lower cost caused an increase in total irrigation water use due to the acreage expansion. This means that if a project had a neutral effect on production but lowered costs that it could lead to expanded allocation of affected land and accompanying emissions within the production category at hand.

5.3.5 Avoided deforestation

In the avoided deforestation case it is often argued that no commodity difference is present along the lines of the test in the previous section. This argument usually asserts that the wood arising from the forests harvested does not enter the market place but rather is burned so there's no effective reduction in commodity availability so the commodity consequences are zero.

However, this is not a sufficient argument for zero leakage as one must also look at what happened in the markets that were stimulating the deforestation. In particular, if the reason for the potential deforestation was that a group wished to enter the cotton market by making an investment in converting forested acreage into cotton, then one must make sure that the resources the individuals intended for use did not flow into a deforestation project outside the project area. Thus, the second statement that must be made is that there's no leakage stimulated in the land market for the potential alternative use. If this test fails, then the magnitude of leakage that arises can be examined using the Kim formula. In particular, one would examine to see if the withdrawal of the land from the project area stimulates leakage somewhere else in the land market. This second test corresponds to Aukland et al's alternative likelihood criteria.

5.4 Spreadsheet implementation

The leakage discount formula discussed above was implemented in the workbook eddiscount.xls under component sheet called **leakage**. Conceptually this sheet can be discussed in terms of inputs, calculations, outputs and saved cases. Two cases are implemented one for the Murray, McCarl and Lee commodity based formula and one for the Kim land based formula.

5.4.1 Commodity based implementation

First for the Murray, McCarl and Lee commodity based formula, the spreadsheet contains an implementation at the top with components as follows.

5.4.1.1 Inputs

Two different types of input are used in the program. The first is portrayed in the screenshot below

	A	B	C	D
1	Commodity based			
2	Input Data			
3				
4	Discount/Interest Rate			4.00%
5	Contract price escalation rate			0.00%
6	Offset price escalation rate			0.00%
7				
8	Supply Elasticity e			0.46
9	Demand Elasticity E			-0.06
10	On premises production			0.045
11	Market production			1
12	Market share (phi)			0.045
13	Offset in project (Cproj)			22.222
14	Offset outside project (Cout)			22.222
15	Price of Offset			30

this is located in the top left corner of the sheet and contains the

- Discount rate (D4) - the real interest-rate used in calculating the present value of items.
- Contract price escalation factor (D5) on a percentage per year basis. Entering 1% in this position reflects contract terms that escalate the offset price paid by the purchaser to the offset producer rise by 1% per year during the length of the contract.
- Offset price escalation factor (D6) on a percentage per year basis. Entering 1% in this position reflects market conditions and damage factors that escalate the market offset price by 1% per year during the entire 100 years.
- Supply elasticity (D8) as defined above.
- Demand elasticity (D9) as defined above.
- Market share (D12) as defined above which is computed from production in the project (D10) divided by the quantity of total market production (D11).
- On-site greenhouse gas offset per unit of production (D13) as defined above.
- Off-site greenhouse gas offset per unit of production (D14) as defined above.
- Base price of the offset (D15).

The second segment of the input consists of the 100 year stream of GHG offset quantities, and market shares. The first 10 years are shown in the screenshot below

	A	B	C	D
18		---- **Annual Data on Project** ----		
19				
20				
21	Leakage			
22		Quantity	Market	
23	Year	Offset	Share	
24	0	1	0.045	
25	1	1	0.046	
26	2	1	0.047	
27	3	1	0.048	
28	4	1	0.049	
29	5	1	0.05	
30	6	1	0.051	
31	7	1	0.052	
32	8	1	0.053	
33	9	1	0.054	
34	10	1	0.055	

Three columns are shown in this data. They are the:

- Number of the year ranging from 0 which is today until 100 and will be used in calculating the discounted terms (column A)
- Yearly project created potential offsets -- the potential offsets produced in a given year which arise from the project and are not cumulative amounts (column B).
- Yearly market share as discussed above (column C).

Note other factors could have been varied over the years, but we chose only to vary market share. We expect that the formula for the time independent leakage discount will be the one most frequently used.

5.4.1.2 Calculations

In order to calculate the discount quantities appropriately, a number of calculations are added and these fall into two cases, time independent calculations, and time dependent calculations. The time independent calculations are discussed under the results section below.

The first 10 years of time dependent calculations are shown in the screenshot just below

	F	G	H	I	J	K	L	M	N	O	P	Q	R
18	------------------------------ Annual Calculations ---------------------------------												
19													
20		Contract	Offset	Contract	Offset						Discounte	Discounte	Discounted
21		Price	Price	Price	Price	This	Non	Non			Cost	Cost	Non
22	Discount	Multiplier	Multiplier	Multiplier	Multiplier	Year	Leaking	Leaking			w/o	with	Leaking
23	Factor	Factor	Factor	Factor	Factor	Leakage	Proportion	Quanitiy	Numerator	Denominat	discount	discount	Proportion
24	1	1	1	1	1	0.880046	0.119954	0.119954	0.119954	1	30	3.668108	0.119954
25	0.961538	1	1	0.961538	0.961538	0.879945	0.120055	0.120055	0.115438	0.961538	28.84615	3.527027	0.115438
26	0.924556	1	1	0.924556	0.924556	0.879844	0.120156	0.120156	0.111091	0.924556	27.73669	3.391372	0.111091
27	0.888996	1	1	0.888996	0.888996	0.879743	0.120257	0.120257	0.106908	0.888996	26.66989	3.260935	0.106908
28	0.854804	1	1	0.854804	0.854804	0.879642	0.120358	0.120358	0.102883	0.854804	25.64413	3.135514	0.102883
29	0.821927	1	1	0.821927	0.821927	0.879541	0.120459	0.120459	0.099008	0.821927	24.65781	3.014917	0.099008
30	0.790315	1	1	0.790315	0.790315	0.87944	0.12056	0.12056	0.09528	0.790315	23.70944	2.898959	0.09528
31	0.759918	1	1	0.759918	0.759918	0.879339	0.120661	0.120661	0.091692	0.759918	22.79753	2.787461	0.091692
32	0.73069	1	1	0.73069	0.73069	0.879239	0.120761	0.120761	0.088239	0.73069	21.92071	2.680251	0.088239
33	0.702587	1	1	0.702587	0.702587	0.879138	0.120862	0.120862	0.084916	0.702587	21.0776	2.577164	0.084916
34	0.675564	1	1	0.675564	0.675564	0.879037	0.120963	0.120963	0.081718	0.675564	20.26693	2.478042	0.081718
35	0.649581	1	1	0.649581	0.649581	0.878936	0.121064	0.121064	0.078641	0.649581	19.48743	2.382733	0.078641

The major columns of this are

- Discount factor (column F) -- present value of a dollar received in year N which is an evaluation of $1/(1+Disc)^N$.
- Contract price multiplier factor (column G) -- this is the extrapolation of the contract price multiplier which is the term $(1+CP)^N$ where CP comes from cell D5 of the spreadsheet.
- Creditable offset price multiplier factor (column H) -- this is the extrapolation of the offset price multiplier which is the term $(1+EP)^N$ where EP comes from cell D6 of the spreadsheet.
- NPV Contract price multiplier factor (column I) -- this is column G times column F.
- Offset price multiplier factor (column J) -- this is column H times column F.
- Annual evaluation of the above leakage formula (column K) -- this uses the elasticity etc data form column D rows 8-14 but lets the annual market share vary according to the year by year data from column C.
- Non leaking proportion (column L) -- which is one minus the leakage in column K.
- Non leaking amount offset (column M) -- which is the leakage discount times the quantity offset by the project (data in columns B time quantity in column L).
- Numerator (column N) -- this is the annual evaluation of the numerator of the discount formula.
- Denominator (column O) -- this is the annual evaluation of the denominator of the discount formula.
- PV annual cost without discount (column P) -- This is the present value of the total cost incurred in a particular year without use of the leakage discount. This is calculated in each year by multiplying the offset price times the relevant yearly offset quantity times the price escalation factor discounted back to present value.
- PV annual cost with discount (column Q) -- This is the present value of the total cost incurred in a particular year with use of the leakage discount. This is calculated in each year by multiplying the offset price times the relevant yearly offset quantity times the price escalation factor times the leakage discount times the offset price escalation factor in turn discounted back to present value.

5.4.1.3 Outputs

Four major classes of outputs are created by the program as shown in the screenshot below

	F	G	H	I	J	K	L	M	N
1									
2									
3	K			1		Cost without discount			765.15
4	Numerator			3.118503		Cost with discount			93.55509
5	Denominator			25.505					
6						NPV Nonleaking quantity			3.118503
7	Results								
8	Time independent leakage			88.00%		Cost/ton no discount			245.3581
9	Time independent price discount			12.00%		Cost/ton with discount			30
10	Time dependent leakage			87.77%					
11	Time dependent price discount			12.23%					

- Time independent leakage discount formula evaluation -- the evaluation of the leakage discount formula derived above appear in column I row 8 (88%) with the resulting price discount equaling one minus the leakage rate is in cell I9 (the price is reduced to 12% of its original value).
- Time dependent leakage discount formula evaluation(I10) -- the evaluation of the time dependent version of the leakage discount formula computed as the ratio of the contract and offset escalation price terms (K from cell I3) times the numerator term (cell I4) divided by the denominator (cell I5). Cell I11 contains the resulting price discount.
- Cost per ton with discount -- amount paid for the prospect if the leakage discount were in effect is reported in cell N9. This consists of the net present value of the cost paid in the presence of a leakage discount (N4) divided by the claimable non leaking part of the offset quantity (N6). This result will equal the original offset price in the presence of zero contract (CP) and offset price (EP) escalation terms and in general will differ when nonzero values for those terms are present.
- Cost per ton without discount -- how much would be paid for the prospect if the leakage discount were not in effect is reported in cell N10. This consists of the net present value of the cost paid in the presence of a leakage discount (N3) divided by the claimable non leaking part of the offset quantity (N6).

5.4.1.4 Saved cases

Finally the spreadsheet contains the data for the cases used above. These appear in columns U-AD.

5.4.2 Commodity based implementation

For the Kim (2004) land based formula the spreadsheet has an implementation starting in row 130 as follows.

5.4.2.1 Inputs

Two different types of input are used in the program. The first one is portrayed in the screenshot below

	A	B	C	D
130	Land based			
131	Input Data			
132				
133	Discount/Interest Rate			4.00%
134	Contract price escalation rate			0.00%
135	Offset price escalation rate			0.00%
136				
137	Supply Elasticity e			0.376
138	Demand Elasticity E			-0.9139
139	Commodity market share (phi)			0.081
140	Project Elasticity of production			1
141	Out of project Elasticity of product			1
142	Ratio of per acre offsets			1
143	Price of Offset			30
144				27.57%

this is located in the top left corner of the sheet and contains the

- Discount rate (D133) - the real interest-rate used in calculating the present value of items.
- Contract price escalation factor (D134) on a percentage per year basis. Entering 1% in this position reflects contract terms that escalate the offset price paid by the purchaser to the offset producer rise by 1% per year during the length of the contract.
- Offset price escalation factor (D135) on a percentage per year basis. Entering 1% in this position reflects market conditions and damage factors that escalate the market offset price by 1% per year during the entire 100 years.
- Supply elasticity (D137) as defined above.
- Demand elasticity (D138) as defined above.
- Commodity Market share (D139) as defined above
- Project elasticity of commodity production with respect to change in project land use (D140) as defined above.
- Off project elasticity of commodity production with respect to change in out of project land use (D141) as defined above.
- Ratio of offsite per acre greenhouse gas offsets to onsite per acre greenhouse gas offsets (D142) --LCR_{out} /LCR_{proj} as above.
- Base price of the offset (D143).

The second segment of input consists of the 100 year stream of GHG offset quantities, and market shares. The first 10 years are shown in the screenshot below

	A	B	C
152	Leakage		Commodity
153		Quantity	Market
154	Year	Offset	Share
155	0	1	0.081
156	1	1	0.081
157	2	1	0.081
158	3	1	0.081
159	4	1	0.081
160	5	1	0.081
161	6	1	0.081
162	7	1	0.081
163	8	1	0.081
164	9	1	0.081
165	10	1	0.081

Four columns are shown in this data. They are the:

- Number of the year ranging from 0 which is today until 100 and will be used in calculating the discounted terms (column A).
- Yearly offset quantity. These data gives the added offsets produced in a given year which arise from the project and are not cumulative amounts (column B).
- Yearly commodity market share as discussed above (column C).

Note other factors could have been varied over the years but we chose only to permit commodity and land market shares. We expect the time independent leakage discount will be the one most frequently used.

5.4.2.2 Calculations

In order to calculate the discount quantities appropriately, a number of calculations are added and these fall into two cases, time independent calculations, and time dependent calculations. The time independent calculations are discussed under the results section below.

The first 10 years of time dependent calculations are shown in the screenshot just below

	F	G	H	I	J	K	L	M	N	O	P	Q	R
149	---------------------------- **Annual Calculations** -------------------------------												
150													
151		Contract	Offset	Contract	Offset						Discounted	Discounted	Discounted
152		Price	Price	Price	Price	This	Non	Non			Cost	Cost	Non
153	Discount	Multiplier	Multiplier	Multiplier	Multiplier	Year	Leaking	Leaking			w/o	with	Leaking
154	Factor	Factor	Factor	Factor	Factor	Leakage	Proportion	Quanitiy	Numerator	Denominat	discount	discount	Proportion
155	1	1	1	1	1	27.57%	72.43%	0.724325	0.724325	1	30	21.72976	0.724325
156	0.961538	1	1	0.961538	0.961538	27.57%	72.43%	0.724325	0.696467	0.961538	28.84615	20.894	0.696467
157	0.924556	1	1	0.924556	0.924556	27.57%	72.43%	0.724325	0.669679	0.924556	27.73669	20.09038	0.669679
158	0.888996	1	1	0.888996	0.888996	27.57%	72.43%	0.724325	0.643922	0.888996	26.66989	19.31767	0.643922
159	0.854804	1	1	0.854804	0.854804	27.57%	72.43%	0.724325	0.619156	0.854804	25.64413	18.57469	0.619156
160	0.821927	1	1	0.821927	0.821927	27.57%	72.43%	0.724325	0.595343	0.821927	24.65781	17.86028	0.595343
161	0.790315	1	1	0.790315	0.790315	27.57%	72.43%	0.724325	0.572445	0.790315	23.70944	17.17334	0.572445
162	0.759918	1	1	0.759918	0.759918	27.57%	72.43%	0.724325	0.550428	0.759918	22.79753	16.51283	0.550428
163	0.73069	1	1	0.73069	0.73069	27.57%	72.43%	0.724325	0.529257	0.73069	21.92071	15.87772	0.529257
164	0.702587	1	1	0.702587	0.702587	27.57%	72.43%	0.724325	0.508901	0.702587	21.0776	15.26704	0.508901
165	0.675564	1	1	0.675564	0.675564	27.57%	72.43%	0.724325	0.489328	0.675564	20.26693	14.67984	0.489328

The major columns of this are

- Discount factor (column F) – present value of a dollar received in year N which is an evaluation of $1/(1+Disc)^N$.
- Contract price multiplier factor (column G) - this is the extrapolation of the contract price multiplier which is the term $(1+CP)^N$ where CP comes from cell D5 of the spreadsheet.
- Offset price multiplier factor (column H) - this is the extrapolation of the offset price multiplier which is the term $(1+EP)^N$ where EP comes from cell D6 of the spreadsheet.
- NPV Contract price multiplier factor (column I) - this is the column G times column F.
- Offset price multiplier factor (column J) - this is the column H times column F.
- Annual evaluation of the above leakage formula (column K) – this uses the elasticity etc. data form column D rows 8-14 but lets the annual market share vary according to the year by year data from column C.
- Non leaking proportion (column L) which is one minus the leakage in column K.
- Non leaking amount offset (column M) which is the leakage discount times the quantity offset by the project (data in columns B time quantity in column L).
- Numerator (column N) - this is the annual evaluation of the numerator of the discount formula.
- Denominator (column O) - this is the annual evaluation of the denominator of the discount formula.
- PV annual cost without discount (column P) - This is the present value of the total cost incurred in a particular year without use of the leakage discount. This is calculated in each year by multiplying the offset price times the relevant yearly offset quantity times the price escalation factor discounted back to present value.
- PV annual cost with discount (column Q) - This is the present value of the total cost incurred in a particular year with use of the leakage discount. This is calculated in each year by multiplying the offset price times the relevant yearly offset quantity times the price escalation factor times the leakage discount times the offset price escalation factor in turn discounted back to present value.

5.4.2.3 Outputs

Four major classes of outputs are created by the program as shown in the screenshot below

	F	G	H	I	J	K	L	M	N
131	Results								
132									
133	K			1		Cost without discount			765.15
134	Numerator			18.47391		Cost with discount			554.2174
135	Denominator			25.505					
136						NPV Nonleaking quantity			18.47391
137	Results								
138	Time independent leakage			27.57%		Cost/ton no discount			41.41786
139	Time independent price discount			72.43%		Cost/ton with discount			30
140	Time dependent leakage			27.57%					
141	Time dependent price discount			72.43%					

- Time independent leakage discount formula evaluation -- the evaluation of the leakage discount formula derived above appear in column I row 138 (27.57%) with the resulting price discount equaling one minus the leakage rate is in cell I139 (the price is reduced to 72.43% of its original value).
- Time dependent leakage discount formula evaluation(I140) -- the evaluation of the time dependent version of the leakage discount formula computed as the ration of the contract and offset escalation price terms (K from cell I133) times the numerator term (cell I134) divided by the denominator (cell I135). Cell I140) contains the resulting price discount.
- Cost per ton with discount -- how much would be paid for the prospect if the leakage discount were in effect is reported in cell N139. This consists of the net present value of the cost paid in the presence of a leakage discount (N134) divided by the claimable non leaking part of the offset quantity (N136). This result will equal the original offset price in the presence of zero contract (CP) and price (EP) escalation terms and is not in general equal to that when nonzero values for those terms are present.
- Cost per ton without discount -- how much would be paid for the prospect if the leakage discount were not in effect is reported in cell N140. This consists of the net present value of the cost paid in the presence of a leakage discount (N133) divided by the claimable non leaking part of the offset quantity (N136).

5.4.2.4 Saved cases

Finally the spreadsheet contains the data for the cases used above. These appear in columns V-AB in rows 133 and below.

5.5 Comments on leakage

Leakage is a phenomenon that can involve some misinterpretations. Several topics merit discussion.

5.5.1 Small projects don't guarantee small leakage

Often people argue that leakage is not a problem for small isolated projects and can be ignored. Such an argument implicitly and improperly assumes small market share and resultant highly elastic excess demand implies no production reaction elsewhere. Actually, when market share is small this generally means production can easily be replaced elsewhere and leads to enhanced leakage. Regions with small market shares do not have market power and do not influence price, thus a change in production induces virtually no change in price (a finding under highly elastic demand). In the Murray, McCarl and Lee base data alteration of the demand elasticity from -0.06 to the highly elastic -10.0 results in a leakage estimate that falls from 88% to 4%. However, the highly elastic demand is often just an artifact of improper market definition. One needs to look at the full market not just a localized market. Thus, while a small region may not influence the timber market that does not mean the market elasticity is highly elastic it just means the regional market share is small. In the Murray, McCarl and Lee base data staying with the original demand elasticity then changing market share from 0.045 to 0.001 does not meaningfully change leakage. One must not get overly carried away with local conditions in evaluating leakage as production response can occur anywhere within the wider market. The demand elasticity must be properly estimated for the full market not just a regional market that exports into a larger market.

5.5.2 Leakage can be quite complex

Projects can have multiple and complex effects. In a project that substitutes timber for rice, one would expect effects in the rice market, the timber market perhaps not until 20-30 years into the future and possibly in other markets if deforestation is stimulated and replaced by other crops. Such complex considerations are best addressed with a complex sector wide model.

5.5.3 Leakage can be negative

Leakage need not only be positive. Production stimulated in other regions can stimulate an emissions reduction outside the project area. If so one may be able to claim offsets above those created by the project.

5.6 Blending multiple offset categories

A project may well involve multiple categories of offsets each with different leakage characteristics. In such case, one needs need to evaluate the discounts that arise for the different components that are reflective of their differing leakage characteristics. Consequently, an evaluation could show leakage for some offset categories but no leakage for emission offsets from say reduced emissions from a manure lagoon that leads to lower amounts of methane or nitrous oxide emissions.

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$$\frac{PriceOffset * \sum_{t=0}^{T} CP_t \; / (1+Disc)^t}{\sum_{t=0}^{T} EP_t / (1+Disc)^t} =$$

$$\frac{\sum_{t=0}^{T} ((1-PermDisc) * PriceOffset * CP_t * QuanOffset_t + PriceOffset * EP_t * BuyBack_t + MainCost_t) / (1+Disc)^t}{\sum_{t=0}^{T} (CP_t * QuanOffset_t) / (1+Disc)^t}$$

define

$$K = \frac{\sum_{t=0}^{T} CP_t / (1+Disc)^t}{\sum_{t=0}^{T} EP_t / (1+Disc)^t}$$

Plug in k

$$PriceOffset * K =$$

$$\frac{\sum_{t=0}^{T} ((1-PermDisc) * PriceOffset * CP_t * QuanOffset_t + PriceOffset * EP_t * BuyBack_t + MainCost_t) / (1+Disc)^t}{\sum_{t=0}^{T} (EP_t * QuanOffset_t) / (1+Disc)^t}$$

divide through by priceoffset

$$K = \frac{\sum_{t=0}^{T} ((1-PermDisc) * CP_t * QuanOffset_t + EP_t * BuyBack_t + MainCost_t / PriceOffset) / (1+Disc)^t}{\sum_{t=0}^{T} (EP_t * QuanOffset_t) / (1+Disc)^t}$$

Mult through by denominator

$$K * \sum_{t=0}^{T} (EP_t * QuanOffset_t) / (1+Disc)^t =$$

$$\sum_{t=0}^{T} ((1-PermDisc) * CP_t * QuanOffset_t + EP_t * BuyBack_t + MainCost_t / PriceOffset) / (1+Disc)^t$$

Expand

$$K * \sum_{t=0}^{T} (EP_t * QuanOffset_t) / (1+Disc)^t =$$

$$\sum_{t=0}^{T} ((1-PermDisc) * CP_t * QuanOffset_t) / (1+Disc)^t$$

$$+ \sum_{t=0}^{T} (EP_t * BuyBack_t + MainCost_t / PriceOffset) / (1+Disc)^t$$

Further expand

$$K * \sum_{t=0}^{T} (EP_t * QuanOffset_t) / (1 + Disc)^t =$$

$$\sum_{t=0}^{T} CP_t * QuanOffset_t / (1 + Disc)^t$$

$$- PermDisc * \sum_{t=0}^{T} CP_t * QuanOffset_t / (1 + Disc)^t$$

$$+ \sum_{t=0}^{T} (EP_t * BuyBack_t + MainCost_t / \Pr iceOffset) / (1 + Disc)^t$$

Move permdisc to left hand side

$$PermDisc * \sum_{t=0}^{T} CP_t * QuanOffset_t / (1 + Disc)^t =$$

$$\sum_{t=0}^{T} CP_t * QuanOffset_t / (1 + Disc)^t$$

$$- K * \sum_{t=0}^{T} (EP_t * QuanOffset_t) / (1 + Disc)^t$$

$$+ \sum_{t=0}^{T} (EP_t * BuyBack_t + MainCost_t / \Pr iceOffset) / (1 + Disc)^t$$

isolate permdisc

$$PermDisc =$$

$$\frac{\sum_{t=0}^{T} CP_t * QuanOffset_t / (1 + Disc)^t}{\sum_{t=0}^{T} CP_t * QuanOffset_t / (1 + Disc)^t}$$

$$- \frac{K * \sum_{t=0}^{T} (EP_t * QuanOffset_t) / (1 + Disc)^t}{\sum_{t=0}^{T} CP_t * QuanOffset_t / (1 + Disc)^t}$$

$$+ \frac{\sum_{t=0}^{T} (EP_t * BuyBack_t + MainCost_t / \Pr iceOffset) / (1 + Disc)^t}{\sum_{t=0}^{T} CP_t * QuanOffset_t / (1 + Disc)^t}$$

COLLAPSE

$$PermDisc =$$

$$1 - \frac{K * \sum_{t=0}^{T} (EP_t * QuanOffset_t) / (1 + Disc)^t}{\sum_{t=0}^{T} CP_t * QuanOffset_t / (1 + Disc)^t}$$

$$+ \frac{\sum_{t=0}^{T} (EP_t * BuyBack_t + MainCost_t / \Pr iceOffset) / (1 + Disc)^t}{\sum_{t=0}^{T} CP_t * QuanOffset_t / (1 + Disc)^t}$$

Additionality

With equal annual offsets

CurentCostPerOffsetTonperfect = $$Offset\Pr ice_0 * \frac{\sum_{t=0}^{T} CP_t / (1+Disc)^t}{\sum_{t=0}^{T} EP_t \ / (1+Disc)^t}$$

CurentCostPerOffsetTon$_{\text{perfect}}$ =

$$\frac{\sum_{t=0}^{T} (Offset\Pr ice_0 * (1 - AdditionalityDiscount) * CP_t * QuanOffset_t + OtherCost_t) / (1+Disc)^t}{\sum_{t=0}^{T} (EP_t * QuanOffset_t * \Pr oportionAdditional_t) / (1+Disc)^t}$$

$$\frac{\sum_{t=0}^{T} CP_t / (1+Disc)^t}{\sum_{t=0}^{T} EP_t \ / (1+Disc)^t} = (1 - AdditionalityDiscount) * \frac{\sum_{t=0}^{T} CP_t * QuanOffset_t \ / (1+Disc)^t}{\sum_{t=0}^{T} EP_t * QuanOffset_t * \Pr oportionAdditional_t \ / (1+Disc)^t}$$

$$\text{AdditionalityDiscount} = 1 - \frac{\sum_{t=0}^{T} CP_t \ / (1+Disc)^t}{\sum_{t=0}^{T} EP_t \ / (1+Disc)^t} * \frac{\sum_{t=0}^{T} EP_t * QuanOffset_t * \Pr oportionAdditional_t \ / (1+Disc)^t}{\sum_{t=0}^{T} CP_t * QuanOffset_t \ / (1+Disc)^t}$$