Managing the Costs of Carbon Release

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The Carbon Tangle

The highly non-linear multi- and inter- disciplinary
study / debate / movement / era
of environmental science.

Who is getting involved in environmental science?

- Biology
- Chemistry
- Physics
- Geology
- Mathematics

And ...

- Political Science
- Sociology
- Economics
- Management
- Recreation and Tourism

"Forest for the Trees" 2010 by Adriane Colburn

One thin September soon
A floating continent disappears
In midnight sun

Vapors rise as
Fever settles on an acid sea
Neptune's bones dissolve

Snow glides from the mountain
Ice fathers floods for a season
A hard rain comes quickly

Then dirt is parched
Kindling is placed in the forest
For the lightning's celebration

Unknown creatures
Take their leave, unmourned
Horsemen ready their stirrups

Passion seeks heroes and friends
The bell of the city
On the hill is rung

The shepherd cries
The hour of choosing has arrived
Here are your tools

- Albert Gore, Jr

- "Gasoline" by Enter the Haggis, 2006.
- "Big Yellow Taxi" by Counting Crows, 2004
- "Earth Song" and "Man in the Mirror" by Michael Jackson, 1997 and 1988.
- "Hole in the Sky" by Black Sabbath, 1975.
- "Wake Up America" by Miley Cyrus, 2008.
- "Pollution" by Bo Diddley, 1972.
- "What About Now" by Daughtry, 2008.

At a time when environmental science, society, and policy are becoming increasingly intertwined, what other areas of expertise should we be leveraging?

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For the universities, what areas outside of science, should our students be studying?

NSF STEP Centers Program (talent expansion program)

"... should be focused on essential concepts in Earth System Science and its foundational importance in areas such as the interplay of environment, energy, and economics. Global climate change and its attendant socio-economic impacts, contaminated and depleted fresh water systems, depleted energy and mineral resources, ocean acidification, declining fish stocks, and loss of biodiversity ...

Difficult decisions that will require full understanding of the unintended consequences for the planet and its societies lie ahead. Undergraduate students majoring in STEM areas as well as students majoring in economics, business, finance, urban planning, political science and other programs need opportunities to gain a thorough understanding of Earth System Science and its relationship to non-STEM fields."

Motivation for Carbon Accounting

With an evolving political environment of commitments to limit emissions of greenhouse gases, and of markets to trade in emissions permits, there is a growing need to accurately evaluate carbon stocks and flows.

"The diverging effects of the suggested accounting methods on national Greenhouse Gas inventories have postponed the inclusion of wood products in the first commitment period of the Kyoto Protocol" (UNECE, 2008).

As of early 2009, draft decisions suggest there are three options for dealing with harvested wood products:

- don't include them at all.
- include them only as delayed emissions of harvests in special cases.
- "create provisions for including harvested wood products".

A decision is/was targeted for a meeting in December 2009.

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Maybe October 2010?

- The stock of carbon in harvested wood products has been contentious.
- Fossil fuel product treatment has developed independently.

Our concern is with properly accounting for how much carbon is actually stored in product stocks, if all carbon products can be brought under the same general framework, how this framework fits into the valuation of carbon release to the atmosphere.

A model for carbon stocks

$$\frac{dS}{dt} = production - removal$$

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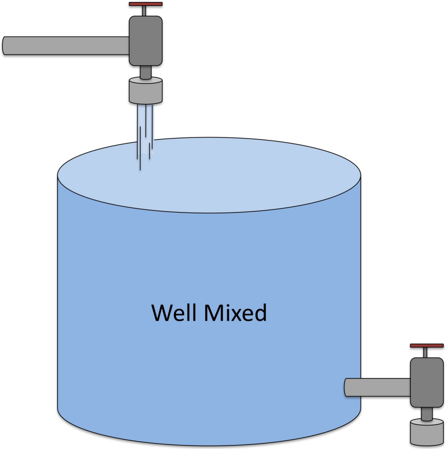
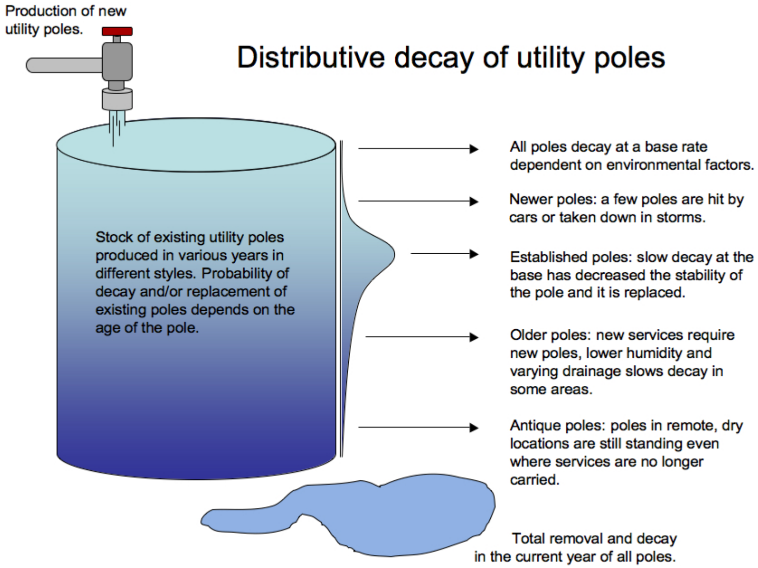
$$\frac{dS}{dt} = J(t) - kS(t)$$


Well Mixed


Production of new
utility poles.
Distributive decay of utility poles
Stock of existing utility poles produced in various years in different styles. Probability of decay and/or replacement of existing poles depends on the age of the pole.
All poles decay at a base rate dependent on environmental factors.
Newer poles: a few poles are hit by cars or taken down in storms.
Established poles: slow decay at the base has decreased the stability of the pole and it is replaced.
Older poles: new services require new poles, lower humidity and varying drainage slows decay in some areas.
Antique poles: poles in remote, dry locations are still standing even where services are no longer carried.
Total removal and decay
in the current year of all poles.

Distributed Decay

Allow products to decay according to the time since production

$$\frac{dS}{dt} = J(t) - \int_0^t J(t-\tau)P(\tau)d\tau$$

The Gamma Distribution

Two parameters which are used to adjust the characteristics of the distribution, k and θ.

Parameter estimates here are calculated based on

- The year of peak decay
- The year by which 95% of the product has decayed

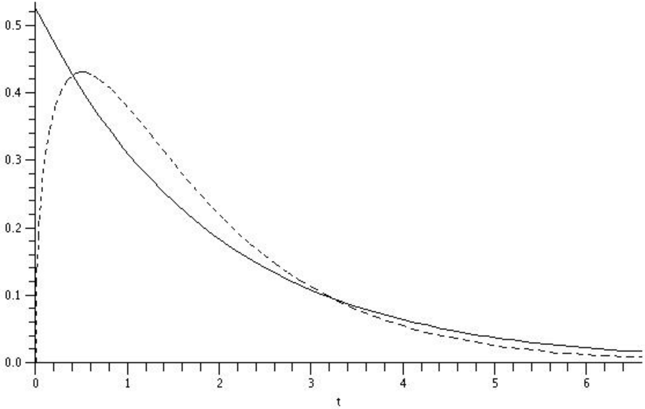
A Generalization Rather Than A Substitution

The single pool model is in fact a special case of the distributed model using the Gamma distribution.

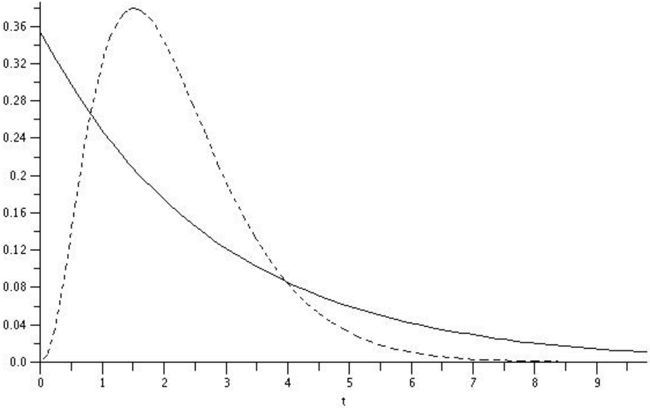
Setting $k = 1$ gives **exactly** the single pool model.

Product (from oak)	Year of max decay	95% decay period (years)	Gamma parameters k	θ
Waste, bark, fuel	2	18	1.305	4.918
Pulpwood	1	5	1.418	1.196
Particleboard	15	40	3.676	5.419
Pallet, packaging	2	5	3.196	0.683
Fencing	40	80	6.662	6.976
Construction	150	300	6.740	26.045
Mining	40	1000	1.128	308.594

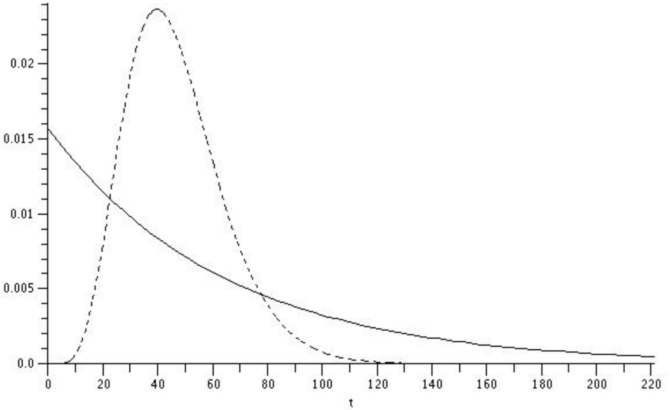
Data courtesy Forest Research, UK



Gamma distributions showing the decay of pulpwood where $k = 1$ and where $k = 1.418$. Both are shown with equal half-lives of 1.319



Gamma distributions showing the decay of pallet and packaging products where $k = 1$ and where $k = 3.196$. Both are shown with equal half-lives of 1.960



Gamma distributions showing the decay of fencing where $k = 1$ and where $k = 6.662$. Both are shown with equal half-lives of 44.171

The Cost of Carbon

Because of discounting, these differences become magnified if there is a cost associated with the release of the carbon to the atmosphere.

- It is accepted that increases of carbon to the atmosphere can change the earth's climate.
- If we assume that these changes are not favorable, we must view those changes as incurring a cost to our society.
- How that cost (i.e. per ton CO_2 equivalent released) is calculated or allocated is a topic for another day.

This cost rests on the shoulders of society

- Costs are likely to be passed on to individuals.
- Treaty signers and governing bodies must administrate any regulations.
- Treaty signers and governing bodies must ultimately organize efforts to ameliorate the incurred costs.

So, we need to calculate the cost, present value or future values of the cost, of releasing carbon and figure out how to pay for those costs.

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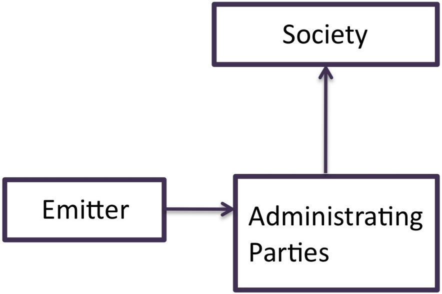
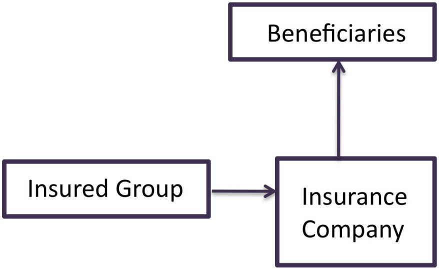
And in steps Dr. Kevin Shirley ...



The Cost of Carbon Emissions



The Cost of Life Insurance

Can we use this analogy, without getting carried away with our comparisons, to our advantage?

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Only if all stake holders have analogous interests.

Insurance

- The people want to care for their beneficiaries.
- The company, taking a management fee, acts as an intermediary.
- The company holds and invests the money so that it is available needed.
- The large size of the group makes it possible.

Carbon

- The emitters want (are required) to invest money to compensate society.
- The administrating parties collects and manages the money.
- The administrating parties plan and organize mitigation and adaptation strategies.

Incentives and motivations

- The beneficiaries prefer that the insured lives a bit longer.
- Society hopes that the release of carbon might be delayed.
- The company and the administrating parties also prefer the delay.

So the parties involved have similar interests. What now?

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Well, what types of questions do life insurance companies ask?

- How much should someone pay for a policy right now?
- What are the payment options?
- What if they change insurance companies?
- What is the policy worth right now?
- How can the policies be bought and sold between companies like mortgages?
- How do I insure against the company's risk?
- How does the company make money?

And for a carbon market?

- How much should someone pay for a contract right now?
- What are the payment options?
- What if they change contracts?
- What is the contract worth right now?
- How can the contract be bought and sold between parties like mortgages?
- How do I insure against risk?
- How does (should) the party make money?

A Tradable Permit System

- Parties issued permits based on some criterion and limit releasing CO_2.
- Parties can purchase or rent permits from other countries.
- Parties only want to pay for carbon that is released.
- Considering these permits to be tradable assets creates the necessity of investigating the financial implications involved.
- Present value needs to be calculated to take into account discounting.
- Need permits for the lifetime of the product (maybe).

Deep breath ...

Deep breath ...

Keep in mind the purpose of the analogy.

The Value of Oxidizing Carbon

Notation:

- A person purchasing insurance at exact age x, (x).
- A bar appears over a variable for continuous variables (or resulting from)
- The age at death random variable, X, the age at which a newborn dies.
- f_X, gives the density of mortality for the newborn or entity (0).
- The probability of (0) dying within n years is then $\int_0^n f_X(t)dt$.

If \$1 of life insurance is to be paid at the instant of death of (0), then to determine an expected cost, the present value is

$$\overline{Z} = e^{-\delta X},$$

where δ is the annualized force of interest used for discounting.

Therefore, the expected present value of the \$1 benefit payment is just the expected value of the random variable $\overline{Z}$, given by

$$\overline{A} = E[\overline{Z}] = \int_0^\infty e^{-\delta t} f_X(t) dt.$$

$\overline{A}$ is referred to as the net single premium, as it represents the expected cost of the benefit paid at the moment of death.

If the benefit varies in time, the present value random variable is

$$\overline{Z}_{b(\cdot)} = b_X e^{-\delta X},$$

where b_X is the benefit if death occurs at age X.
Then net single premium is $E[\overline{Z}_{b(\cdot)}]$.

For carbon release, the the present value of the cost per unit of emitted CO_2 in year T is

$$\overline{Z}_b = b_T e^{-\delta T}$$

where δ is the assumed long term annual force of interest used for discounting. Therefore, the expected present value of the cost of 1 unit of emitted CO_2 is

$$\overline{C} = E[b_T e^{-\delta T}] = E[be^{(r-\delta)T}] = \int_0^\infty be^{(r-\delta)t} P(t) dt \quad (1)$$

If $J(t)$ represents the production at time t, the total expected present value of the cost of this single cohort of wood stock is

$$J(0)\overline{C}$$

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(the cost scales)

Payment Plans

To spread the funding over n years. solve for the level payment, P, in the equation

$$P\bar{a}_{\overline{n}|} = J(0)\overline{C}$$

Where $\bar{a}_{\overline{n}|}$ is the present value of an annuity of \$1 for continuous payments for a term of $n-$years.

Notice that one affect of discounting is that paying the full amount up front costs less than spreading the payments over several years.

Years to Pay (k)	k-year Annuity Due $\ddot{a}_{\overline{k|}}$	Payment
1	1	$41.78
5	4.630	$ 9.02
10	8.435	$ 4.95
15	11.563	$ 3.61

The initial cost is $b = \$50$ per ton of CO_2, the inflation rate for CO_2 is $r = 2\%$, a long term continuous discount rate, $\delta = 5\%$, the short term annual discount rate for the annuities is $i = 4\%$, and the units of production are $J(0) = 1$ (in tons CO_2).

Short Term Contracts

An *n*-year renewable term model

- Shorten the horizon for renegotiation or revisiting assumptions.
- Valuable when actuarial data are lacking and costs are still being defined.
- A 1-year term model is a pay-as-oxidization occurs model.
- Allows for more frequent trading of the carbon sequestered in certain stocks.

$$\overline{Z}_n = \begin{cases} e^{-\delta T} & , 0 \leq T \leq n \\ 0 & , T > n \end{cases}$$

The expected cost over the initial term period is given by

$$\overline{C}_{0:n} = E[b_T \overline{Z}_n] = \int_0^n b_t e^{-\delta t} P(t) dt \tag{2}$$

The cost for CO_2 emissions beyond the term period is then considered at the time of renegotiation.

The cost over the next n-years can be found,

$$\overline{C}_{x:n} = \int_0^n b_{x,t} e^{-\delta_x t} f_T(t) dt$$

$$\overline{C} = \sum_{k=0}^{\infty} e^{-\delta k} \int_k^{\infty} P(t)dt \, \overline{C}_{k:1}$$

$e^{-\delta k}$ is the discount factor discounting back to time $t = 0$, $\int_k^{\infty} P(t)dt$ is the expected percentage of stock left undecayed at time $t = k$, and $\overline{C}_{k:1}$ is the one year term cost per ton of CO_2 emitted during the time interval $t = k$ to $t = k + 1$ (year $k + 1$) from the stock that has been exposed to the decay hazard for $k-$years and survived.

The term costs below illustrate 1-year term costs for three different wood products

Year	Waste, bark, fuel	Pulpwood	Fencing
1	\$4.69	\$19.08	$\$4.0x10^{-8}$
2	\$5.81	\$14.95	$\$3.6x10^{-6}$
3	\$5.68	\$8.28	$\$4.6x10^{-5}$
4	\$5.25	\$4.23	$\$2.5x10^{-4}$
5	\$4.72	\$2.08	$\$9.0x10^{-4}$
PV Total Cost	\$23.74	\$46.15	$\$1.0x10^{-3}$
5-year Term	\$23.74	\$46.15	$\$1.0x10^{-3}$

Assume 1 ton of production (tons CO_2 potential), initial cost $b = \$50$ per ton CO_2, inflation rate in the cost of CO_2, $r = 2\%$ and a long term continuous discount rate, $\delta = 5\%$.

Deferred Contracts

A deferred cost model can be used to divide the contract among multiple traders.

$$\overline{C} = \overline{C}_{0:n} +_n |\overline{C}.$$

Hence $\overline{C}_{0:n}$, could be traded to one party and ${}_n|\overline{C}$ from the same stock could be traded to a different party.

$${}_n|\overline{C} = e^{-\delta n} \int_n^\infty P(t) dt \, \overline{C}_{n:\infty}.$$

Product Usage	5-year Term Cost, $\overline{C}_{0:5}$	5-year % Remaining	5-year Deferred Cost, ${}_{5}\lvert\overline{C}$	Total Cost $\overline{C}$
Waste, bark, fuel	\$23.74	48.95%	\$18.04	\$41.78
Pulpwood	\$46.15	3.42%	\$1.41	\$47.56
Fencing	$\$1.001 \times 10^{-3}$	99.99%	\$14.10	\$14.10

Continued Production

The expected cost due to the production function $J(\cdot)$.
The expected decay at time u due to the production from time $\tau = 0$ to $\tau = u$. Is given by

$$\int_0^u J(t-\tau)P(\tau)d\tau$$

Assuming the cost per unit of CO_2 at time u is $b_u = be^{ru}$, then the expected cost for the decay at time u discounted back to $t = 0$ is

$$be^{(r-\delta)u}\int_0^u J(u-\tau)P(\tau)d\tau$$

Therefore, the total discounted expected cost due to the production $J(\cdot)$ is found by accumulating the costs continuously

$$C_J = \int_0^\infty be^{(r-\delta)u} \int_0^u J(u-\tau)P(\tau)d\tau du$$

Finally,

$$C_J = \int_0^\infty e^{(r-\delta)t} J(t) \int_0^\infty be^{(r-\delta)\tau} P(\tau)d\tau dt$$

$$C_J = \int_0^\infty e^{-\delta t} J(t)\overline{C}dt$$

Valuing the Contract

Calculate the future liability that the contract has to the company and take this as a proxy for the contract value.

This is normally stated as the present value of future benefits minus the present value of future premiums PVFB-PVFP.

In the context of the cost of CO_2 emissions, the term PVFB is the expected present value of the future cost of emissions covered by the contract. The term PVFP is the present value of future payments that the party providing the funding has yet to make on the contract.

As an example, assume the cost of the contract is given by $\$\overline{C}$ for 1 ton (tons CO_2 potential) beginning January 1, 2010. The party funding the cost has agreed to pay 5 equal annual installments, $\$P$, beginning January 1, 2010. On December 31, 2011, the value of the contract to the funder is

$$V = \left[\int_2^\infty P(t)dt\right] \int_0^\infty [be^{r2}]e^{(r-\delta)(\tau)} \frac{P(\tau+2)}{\int_2^\infty P(t)dt} d\tau - P\ddot{a}_{\overline{3|}}$$

$\left[\int_2^\infty P(t)dt\right]$ is the amount of CO_2 still sequestered from the original stock of 1 ton (tons CO_2 potential), $[be^{r2}]$ is the price of CO_2 on December 31, 2011, and $\frac{P(\tau+2)}{\int_2^\infty P(t)dt}$ is the future lifetime distribution for the CO_2 still sequestered.

Error and Sensitivity

$$\text{Charge} = \text{Present Value} + \text{Risk Charge}$$

Reflects the cost in the variation of the estimations in the calculations and in economic growth.

In the case of carbon, there are three primary sources of error that will each contribute to the risk charge.

Sources of error

- Economic forecasting.
- Shadow price estimation.
- Parameter estimation.

For the first two cases we defer to a future paper.

In the third case, we make a few preliminary calculations.

Wood Product	Distr. Parameters		Present Value of Emissions		
Usage	k	θ	Expected	1% error	10% error
2% discounting					
Waste, bark, fuel	1.305	4.918	$ 44.24	± $0.11	± $1.10
Pulpwood	1.418	1.196	$48.35	± $0.03	± $0.34
Particleboard	3.676	5.419	$34.25	± $0.26	± $2.54
Pallet and Packaging	3.196	0.683	$47.88	± $0.04	± $0.43
Fencing	6.662	6.976	$ 20.95	± $0.36	± $3.65
Construction	6.740	25.045	$2.96	± $0.16	± $1.89
Mining	1.128	308.594	$ 5.42	± $0.17	± $1.99
5% discounting					
Waste, bark, fuel	1.305	4.918	$33.99	± $3.74	± $5.55
Pulpwood	1.418	1.196	$46.14	± $0.17	± $0.87
Particleboard	3.676	5.419	$20.71	± $0.35	± $3.58
Pallet and Packaging	3.196	0.683	$44.91	± $0.10	± $0.99
Fencing	6.662	6.976	$ 6.81	± $0.26	± $2.92
Construction	6.740	25.045	$0.18	± $0.02	± $0.14
Mining	1.128	308.594	$ 2.13	± $0.09	± $1.09

Long term sequestration projects will include a much larger risk charge than short term projects.

Shorter term contracts, even for long term storage, will include much smaller risk charges because the forecasting is more accurate.

Conclusions

- Generalization of current methods.
- Flexible implementation, from simple to sophisticated.
- Applicable to any carbon containing product.
- Natural extensions using an established theoretical foundation.

Pending Questions

- How do we handle extremely long-lived products?
- What does "permanent" sequestration mean?
- Are there spatial effects?
- How can we implement these ideas?

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