A bioeconomic model of carbon trading in an Alberta grazing business

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Abstract

Biosequestration of carbon on agricultural land has been confirmed as a source of offsets under international greenhouse gas emission agreements. Technical studies have identified the biological potential supply from different practices but not the economically efficient level of supply. From a landholders' perspective the decision to participate in a carbon trading scheme will be dependent on the relative profitability of carbon trading compared to their status quo enterprise as well as their perception of the risks involved. Integral to this decision is the extent to which variation in opportunity costs, transaction costs and other variables will affect relative returns. Bioeconomic modelling has successfully been applied to many agricultural problems and it is also becoming a more commonly used tool in environmental conservation decisions. The capacity of the method to apply sensitivity analysis on both ecological and economic variables is particularly useful in cases such as carbon trading where historical data is not available and substantial uncertainty exists. This study uses a case study of beef production in Alberta to test the relative profitability of two alternative means of producing carbon offsets under a range of input variables.

Introduction

In Canada, agriculture accounts for approximately eight per cent of Gross Domestic Product (GDP) (Kittson 2009) and approximately 9.5 per cent of Canadian greenhouse gas emissions. The primary sources of agricultural emissions are nitrous oxide from crop production and methane from beef and dairy cattle. Although a major contributor to emissions, there are also potential opportunities to develop carbon offsets from the industry. Three key sources of potential offsets have been identified: forestry, agriculture and landfill (Government of Canada 2003). At the national level these options have been estimated to be capable of providing up to 10 million tonnes of CO_2^{-e} offsets per year at a carbon price of approximately $10 to $15 per tonne (Government of Canada 2003). Given the expected high dependency on soil and forestry several efforts have been made to identify geographically those areas which are most likely to be capable of supplying cost-effective offsets (see for example McKenney et al. 2004; Yemshanov et al. 2005). Results have varied with one study estimating that only 100 000 hectares of the land most suited to afforestation would provide a sufficient investment return to induce conversion (Canadian Forest Service 2006) whilst others have identified vast areas of potentially forested land.

The estimated cost per tonne of reducing emissions varies widely depending on the strategy. Adoption of those strategies which have a negative cost per tonne is expected to increase profitability while the costs of other options range from approximately $7 to over $300 per tonne CO_2^{-e} (Weersink & Brown 2000). The greatest opportunities for sequestration, particularly at low cost per tonne are in the prairie regions with conservation tillage (Meyer-Aurich et al. 2006) however carbon stored in this manner is only a temporary offset and the potential for negative costs per tonne may conflict with additionality requirements.

These studies provide broad estimates of the potential for agriculture land to provide carbon offsets but do no consider the variation in opportunity costs, transaction costs, sequestration rates and carbon prices which vary across different areas and the effect these have on the relative profitability of a carbon enterprise as opposed to the current enterprise. This paper presents a bioeconomic model based on an Alberta case study which was designed to test the effect of these variables and estimate the minimum carbon price at which changing practices to sequester carbon could be profitable.

Sources and supply of offsets in Alberta

Alberta was one of the first economies in the world to implement a formal carbon trading system and has set more ambitious reduction targets than the minimum required under Kyoto. Emissions in Alberta are regulated under the *Specified Gas Emitters Regulation* which has created demand for offsets. A range of protocols for different offsets are in place, including methods for creating offsets from manure management, reduced tillage, alternative beef feeding strategies and reduced nitrous oxide emissions. Protocols also exist for non-agricultural production activities including solar and wind energy projects. The protocol for afforestation has been de-activated while it is upgraded to better account for the carbon that remains stored in wood after harvest (Haugen-Kozyra & Mihajlovich 2010). Based on earlier protocols and estimates it is predicted that Alberta could supply approximately one mega tonne of CO_2^{-e} offsets per year through afforestation (Haugen-Kozyra & Mihajlovich 2010). However, the most cost effective greenhouse gas emissions reductions can be achieved by increasing the area of permanent cover (replacing cropping with permanent pasture) although this method does not supply large quantities of reductions or offsets. The greatest source of reductions is achieved through a range of grazing strategies including a reduction in stocking rate and rotational grazing. Assuming a total adoption rate of 35% by 2010, this practice would have reduced emissions by approximately 6.84 Mt CO_2^{-e} at an average negative cost of $3.81 per tonne (Weersink & Brown 2000). The negative cost is a reflection of the higher pasture productivity and corresponding lower feed costs expected under this scenario.

Forestry and pasture management appear to be the most likely significant sources of carbon offsets, thus they form the basis of the case study.

Theoretical framework

Bioeconomic modelling developed out of the need to meet increasing demands for agricultural products in a sustainable manner. The methods were initially applied in fishing and forestry economics to estimate maximum sustainable harvest and maximum sustainable yield. To achieve the desired efficient allocation of resources requires integrated systems which use a single set of variables to drive ecological, economic and social components (Kruseman & Bade 1998; Ruben et al. 1998; Mohamed et al. 2000; 2002). More recently bioeconomic models have been used to design (see for example Khan et al. 2000; Cacho et al. 2001) and estimate the impacts of policies aimed at increasing the supply of environmental values from agricultural systems (Donaghy et al. 2009; Star & Donaghy 2009). These models include agricultural production, climate, economic, environmental and social value variables to construct sophisticated estimates of the outcomes of alternative scenarios driven by policy, economic or climatic factors.

Model

The bioeconomic model was constructed using the framework developed for a similar case study based on the Queensland (Australia) beef industry. Two sub-models are based on different strategies to sequester carbon; forestry and improved grazing land management. The model is constructed at the plot scale.

The model compares the business as usual scenario, i.e. cattle production, no carbon sequestration and no requirement to account for carbon emissions to; planting trees for the purpose of carbon sequestration or establishment of rotational grazing. The model allows for the testing of a range of policy settings, prices and transaction costs. The economic component of the model is based on the assumption that a landholder maximises present value (I) of sum of the stream of annual payments from cattle and carbon production. The present value function is:

$$I = \sum_{n=1}^{N} [(GMAE) + h(CPS_n)](1 + r^{-n}) \quad (1)$$

Where N is the decision period in years

GM is the Gross Margin per Adult Equivalent for cattle production

AE is the stocking rate in Adult Equivalents for the enterprise

CP is the carbon price

S is the amount of carbon sequestered (tonnes of CO_2^{-e}/ha)

h is the area of the enterprise (hectares)

r is the discount rate

s is the carbon sequestration enterprise

Forestry

Historically plantation forestry has often been only a marginally attractive investment option in Canada (Yemshanov et al. 2007) however the inclusion of carbon offsets as an additional source of value has changed this result for many areas. Extensive work has already been undertaken to evaluate the economics of these alternatives at very detailed geo-spatial scales. These models provided detailed estimates of carbon sequestration rates and costs which were used in the case study. The advantage for landholders in Canada is that these specific models could be used to estimate the likely profitability of carbon sequestration for their enterprise. The availability of information including the results of trials specific to the issue has been shown to significantly affect rates of adoption (Pannell et al. 2006).

Forestry case study

The afforestation scenario is based on hybrid poplar as this faster growing species has been identified as the most suitable for carbon sequestration (Yemshanov et al. 2005; Yemshanov et al. 2007; Yemshanov & McKenney 2008). The Chapman Richards function (van Kooten et al. 2000) is used to estimate carbon sequestration. This method estimates carbon sequestration as a function of tree growth rate which is then converted to biomass then carbon. The equations are shown below. Carbon emissions from plantation establishment, maintenance and harvest were subtracted from the gross carbon sequestered to calculate net carbon sequestration. Other assumptions as used in the case study are shown in Table 1.

Growth function: $$v(t) = A(1 - e^{-kt})^m \quad (2)$$

Above ground biomass $$(G) = 1.57v \quad (3)$$

Root biomass $$(R) = 0.2317G \quad (4)$$

Carbon $$(C) = 0.207G + 0.207R \quad (5)$$

A is maximum stem wood volume

t is time in years

k and *m* are parameters

Table 1 Forestry Assumptions

	Hybrid poplar	Source
A	270	(van Kooten et al. 2000)
k	0.143	
m	3.0	
Contract length (years)	20	
Forest establishment costs ($/ha)	$2,000	(Yemshanov et al. 2005)
Forest harvesting costs ($/m3)		(Yemshanov & McKenney 2008)
maintenance ($/ha/yr)	$10	
Rotation (yrs)	15-30	(Yemshanov et al. 2005)
timber value ($/m3)	$11	
Pulp wood price ($/m3)	$9	
% pulpwood	85%	
Harvest emissions (tC ha-1yr-1)	0.252	
Planting emissions (tC ha-1yr-1)	0.05	(Updegraff et al. 2004)
Maintenance emissions (tC ha-1yr-1	0.36	
Timber value ($/m^3)	$20	(Yemshanov et al. 2005)

As discussed in the previous section extensive work has already been conducted to estimate the potential returns from carbon forestry in many difference areas of Canada. This case study was not designed to handle the variation in tree growth rates, sequestration rates, timber values and costs which have been incorporated into specific forestry models. Rather, it was designed to evaluate the effect of variation in opportunity costs, transaction costs and other variables on the relative profitability of carbon sequestration versus the status quo agricultural production.

One of the major areas of contention with regard to using forestry to produce carbon offsets is that of permanence. Carbon offsets produced by biosequestration are subject to potential emissions either when timber products are harvested or if trees are destroyed as a result of fire, pests or disease. Most offset programs have suggested some form of insurance scheme or buffer amount to protect against unplanned events such as fire. However, there is ongoing debate as to how to account for the carbon stored in harvested timber products. Some programs have previously assumed that all carbon sequestered is immediately re-emitted upon harvest whilst others have assumed zero net emissions assuming that the forest is immediately replanted. The forestry protocol for the Alberta Offset Scheme has been suspended whilst a decision is made on the proportion of wood which is assumed to remain sequestered and over what time period that carbon may be emitted. In the absence of a clear ruling the case study will conduct sensitivity analysis to analyse the impact that different assumptions will make. The base case will assume that 100% of carbon sequestered is re-emitted and permits for such emissions must be purchased at the same rate that permits were sold.

Rotational grazing

As discussed rotation grazing has been identified as a potentially significant source of carbon offsets. Rotational grazing to sequester carbon involves switching from a set stocking grazing system to one in which cattle are rotated through smaller paddocks based on feed availability. The improvement in soil carbon comes about through better pasture management which results in greater pasture growth as well as increased fertility. This type of grazing system is also expected to increase the productive capacity of pasture.

Measuring the amount of additional carbon sequestered by changing grazing management from continuous stocking to rotational grazing is difficult and expensive, thus few accurate estimates exist and improvements in measuring technology and models are likely to change estimates in the future. For the purposes of this case study sequestration estimates were taken from Boehm et al (2004) which are the most accurate and detailed available. Based on the earlier assumption of a centrally located case study the sequestration rate for the Aspen Parkland seeded pastures of $0.33tCO_2ha^{-1}yr^{-1}$ was used.

To implement a rotational grazing system will require investment in additional fencing and watering which will incur additional annual maintenance costs. The value of additional fencing and watering is assumed to be zero at the end of the 20 year discount period. Weersink and Brown (2000) estimated conversion costs of $73 per hectare for establishment fencing and watering in Year 0, $14.60 for additional annual maintenance and $146 per hectare every five years for re-seeding[1]. Using these costs the NPV for rotational grazing, without carbon payments is lower than the NPV for the status quo grazing system. However many producers have implemented rotational grazing in the absence of carbon payments which suggests that conversion can be achieved at lower costs. For the purposes of the analysis, reseeding costs were reduced by 50 per cent with sensitivity analysis conducted a higher levels.

[1] Original 2000 prices were converted to 2011 prices assuming a 3.5% inflation rate

Unlike the forestry option cattle production is maintained in this scenario therefore there are no avoided methane emissions to be counted. As a result of the higher stocking rate total methane emissions will actually increase, although this may be offset slightly due to the higher digestibility of the feed which is being consumed. Reliable estimates of the extent to which better feed conversion may occur are not available therefore for the purposes of this case study it is ignored. In the base scenarios methane emissions are ignored completely but sensitivity analysis is conducted to examine the impact if methane is subtracted from total sequestration to calculate net sequestration traded.

Cattle Production

Cattle production parameters were taken from averages published by Agriculture and Rural Development Alberta. The majority of cattle production is in the southern and central part of Alberta but far south eastern areas are considered too dry for tree production thus the case study is based on a generally centrally located plot with an average annual rainfall of 450 – 550mm and assuming 'Good' pasture condition.

The status quo grazing operation is assumed to involved set stocking according to long term carrying capacity. Average stocking rate is assumed to be 0.57 Animal Units per Month per hectare[2] (AUM) (Hand & Lopetinsky 1998). AUM is the standard animal unit used in Alberta and aligns with the same weights as used to estimate Animal Equivalents for the Queensland case study. For the rotational grazing carbon offset option stocking rates are assumed to be one rainfall class higher than the base model at 0.89 AUM per hectare (as recommended by Hand & Lopetinsky 1998). Pasture in Alberta is not available year round

[2] Hand and Lopetinsky Hand, R. & Lopetinsky, K. 1998. *Grazing tame pastures effectively*. Agriculture, F.a.R.D., Edmonton. Available from: http://www.mbforagecouncil.mb.ca/Forage%20Manual%20Article/8-0%20Pasture%20Management/8-1%20Grazing%20Management%20Systems/8-1-12%20%20Grazing%20tame%20pastures-AB%20Agric.pdf, viewed 5 October 2011. report AUM per acre. For consistency with the Queensland case study rates were converted to per hectare assuming 0.40 hectares per acre.

therefore using the gross margin of cattle production per annum on pasture is not an accurate measure of the opportunity costs of carbon sequestration. A more accurate measure is the cost of pasture leasing which is a common practice in Alberta. Surveys collected by Agriculture and Rural Development Alberta provide estimates of the average cost of pasture rental. In 2008 and 2009 rates varied between $15 and $33 per AUM for Central Alberta with an average of $25.42AUM. Assuming an average grazing season of five months, the total annual value is $127.08 per animal unit.

A starting price of $15 per tonne was used in the initial analysis as this is the cost of carbon emission permits in Alberta (Government of Alberta 2007). The plot area was set at 100 hectares (240 acres) to reflect average farm size.

The model is based only on variable costs and does not include any changes to fixed costs over the short or long term. Fixed costs of land ownership such as interest payments and council rates will not change as a result of a change in enterprise. Some other fixed costs in a cattle enterprise are 'lumpy', that is, they do no change with small changes in cattle numbers, thus are not variable costs but may change with significant changes in cattle numbers. A common example is permanent labour. A small change in numbers, for example from 100 to 90 head is unlikely to change permanent labour requirements. However a reduction from 100 to 50 head would likely reduce the amount of permanent labour required. For simplicity it is assumed that these costs do not change.

Results

The assumptions for the base case are shown in Table 2. These assumptions are used as the standard against which all sensitivity analyses are done. In each of the sensitivity analyses only the indicated variable is changed, all others remain as described below.

Table 2 Bioeconomic model base assumptions - Canada

Base model	Cattle	Forestry	Rotational Grazing
Discount rate	6%	6%	6%
Plot size (ha)	100	100	100
Starting year	2011	2011	2011
Cattle GM ($/AE)	$127	NA	$127
Stocking rate (AE/ha)	0.57	NA	0.89
Include methane emissions (Y/N)	No	No	No
Rotation length (yrs)	NA	20	NA
Is timber harvested?	NA	Yes	NA
Practice implementation costs ($/ha)	NA	$1500	$73
Contract establishment costs ($/contract)	NA	$2000	$2000
Annual monitoring costs ($/ha)	NA	$10	$10
Contract length (yrs)	20	20	20
Carbon price ($/t CO2-e)	NA	$15	$15

Forestry

The first set of results compares identical 100 hectare plots of land under either status quo cattle grazing or forestry over 20 years using the base assumptions as described above. The 'Base case' columns in Table 3 report the NPV for both enterprises under this scenario, showing the difference in the forestry option results when timber is harvested or not. The additional columns compare NPV under changes to a selection of variables. These first sensitivity analyses were used to identify the variables of interest to be tested further using the optimization model.

Under the base case assumptions the cattle option is more profitable than the forestry option. This applies whether the timber is harvested or not, and indifferent to the assumed emissions at harvest. Even if the cattle value is only half the base value (scenarios 5 and 7), the cattle enterprise is more profitable than the carbon enterprise at carbon prices of $15 per tonne. Harvesting costs are a significant component of the analysis thus the NPV for harvested timber is always less than for non-harvested even if 100 per cent of the carbon sequestered is assumed to remain in the harvested wood products (scenario 4) This is consistent with the studies already reviewed on forestry investments in Canada which found that commercial forestry does not become attractive without carbon benefits and then only at relatively high carbon prices.

As shown in Figure 1, the NPV for the forestry option does not become positive until the carbon price reaches $25 per tonne. Only at a carbon price of greater than $60 per tonne does the NPV for forestry exceed that of the status quo grazing operation.

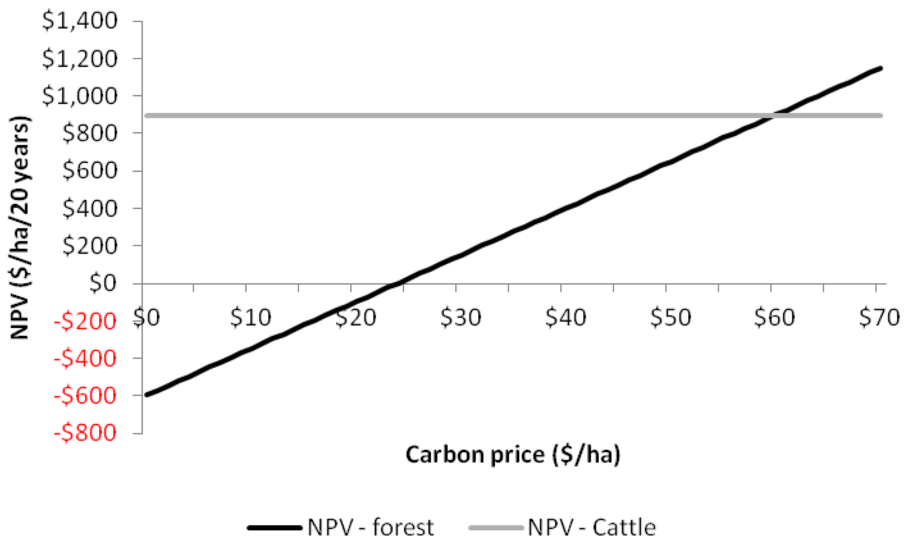

Figure 1 Sensitivity to carbon price (forestry)

Table 3 Comparisons of NPV - Cattle and Carbon (Forestry)

Scenario	1	2	3	4	5	6	7	8
	Base case		50% carbon retained at harvest	100% carbon retained at harvest	Low cattle value	High cattle value	Low cattle value	High cattle value
	Timber not harvested	Timber harvested	Timber harvested				Timber not harvested	
Discount rate	6%	6%	6%	6%	6%	6%	6%	6%
Plot size (ha)	100	100	100	100	100	100	100	100
Starting year	2011	2011	2011	2011	2011	2011	2011	2011
Cattle value ($/AE)	$127	$127	$127	$127	$64	$191	$64	$191
Include methane emissions (Y/N)	No	No	No	No	No	No	No	No
Rotation length	20	20	20	20	20	20	20	20
Carbon (t)	922	393	4 920	9 448	393	393	393	393
Contract establishment costs ($/contact)	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000
Annual monitoring costs ($/ha)	$10	$10	$10	$10	$10	$10	$10	$10
Contract length (years)	20	20	20	20	20	20	20	20
Carbon price ($/t CO2-e)	$15	$15	$15	$15	$15	$15	$15	$15
% emissions at harvest	NA	100%	50%	0%	100%	100%	100%	100%
NPV cattle	$60,193	$60,193	$60,193	$60,193	$30,096	$90,289	$30,096	$90,289
NPV forestry	$14,359	($30,558)	($9,382)	$11,794	($30,558)	($30,558)	$14,359	$14,359

Optimization results

For a landholder, the decision to participate in a carbon offsets model is two step; first the decision to participate, secondly the decision as to how many carbon offsets to supply. The model and results above compare the outcomes of the first part of the decision. To answer the second part of the question requires analysis at the enterprise scale to determine the optimal enterprise mix between cattle and carbon. The model assumes a single decision point and constant allocation for the decision period.

Modifying equation (1) , the NPV under a given allocation to each enterprise is given by:

Forestry

$$I = \sum_{n=1}^{N} \left[\left(h_g SR_g GM \right) + \left(h_c SCP \right) \right] \left(1 + r^{-n} \right) \quad \textbf{(6)}$$

Rotational Grazing

$$I = \sum_{n=1}^{N} \left[\left(h_g SR_g GM \right) + \left(\left(h_c SR_c GM \right) + \left(h_c SCP \right) \right) \right] \left(1 + r^{-n} \right) \quad \textbf{(7)}$$

where *g* denotes a grazing only enterprise and *c* denotes a grazing and carbon enterprise.

The optimisation is calculated using the Microsoft Excel Solver and Visual Basic for Excel. All scenarios are based on a 100 hectare parcel of land which is homogenous in land-type, carrying capacity and carbon sequestration potential across the parcel. Each iteration reports the minimum carbon price at which optimal allocation (as measure by maximized total NPV) to the cattle-carbon enterprise becomes positive.

Under the base assumptions comparing the status quo cattle enterprise to forestry, the optimal allocation to maximise NPV is 100% to the cattle enterprise until carbon prices reach $63 per tonne. At carbon prices greater than $63 per tonne the optimal allocation is 100% to the carbon forestry enterprise. If the timber is not harvested, harvesting costs and emissions are eliminated which lowers the minimum price to induce forestry establishment to $42 per tonne. This scenario assumes that the carbon sequestered over the contract period would be traded. At the end of the contract period the contract and the payments would cease with no further liability for either the buyer or seller. This scenario is less likely to occur in reality however it offers an interesting comparison of the effects of harvesting costs and emissions on the viability of carbon forestry investments.

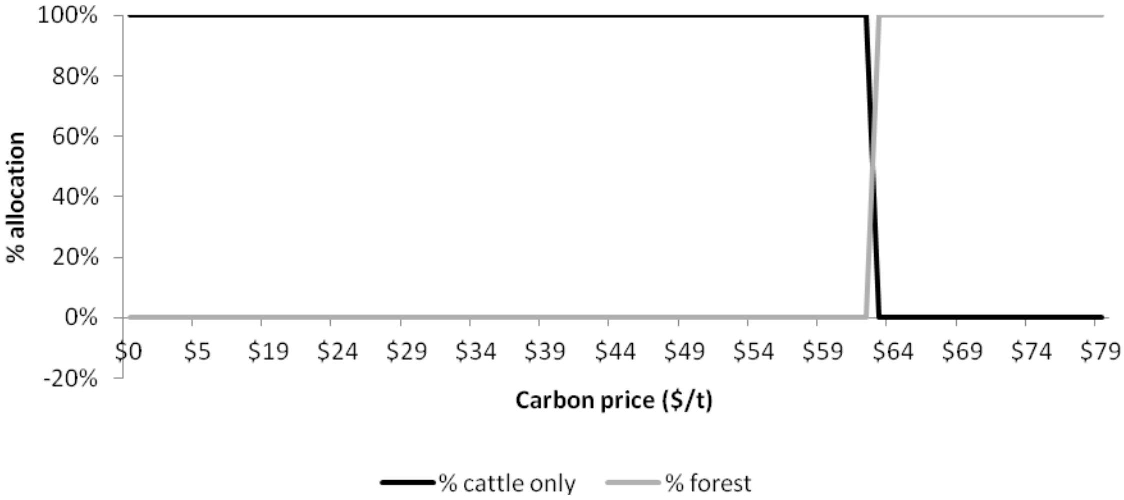

Figure 2 Optimal allocation under base assumptions (forestry)

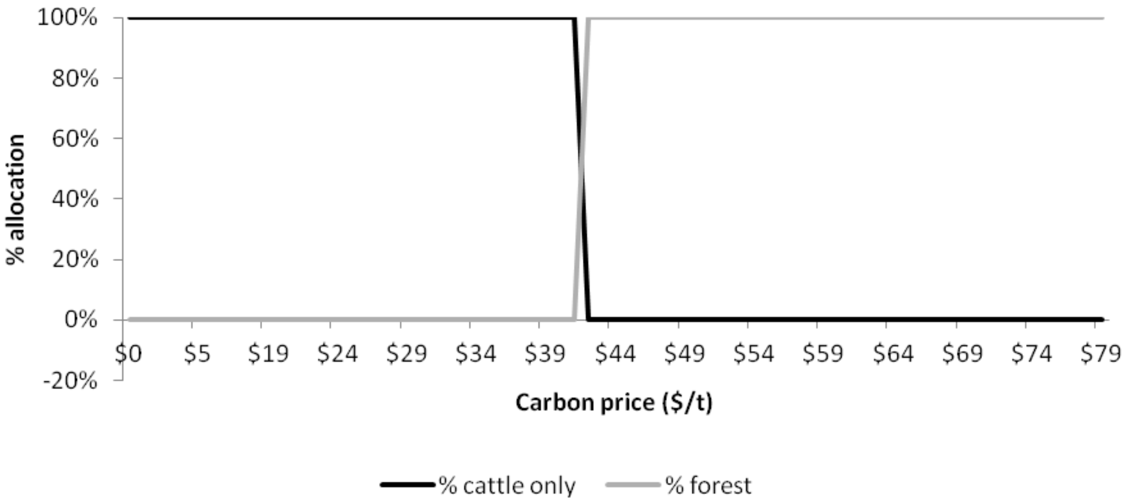

Figure 3 Optimal allocation - timber not harvested (forestry)

Transaction costs

As expected, higher annual transaction costs increase the carbon price at which the forestry scenario is more profitable than the cattle option. If the timber is not harvested, net carbon sequestered is higher, resulting in a lower required price to induce participation.

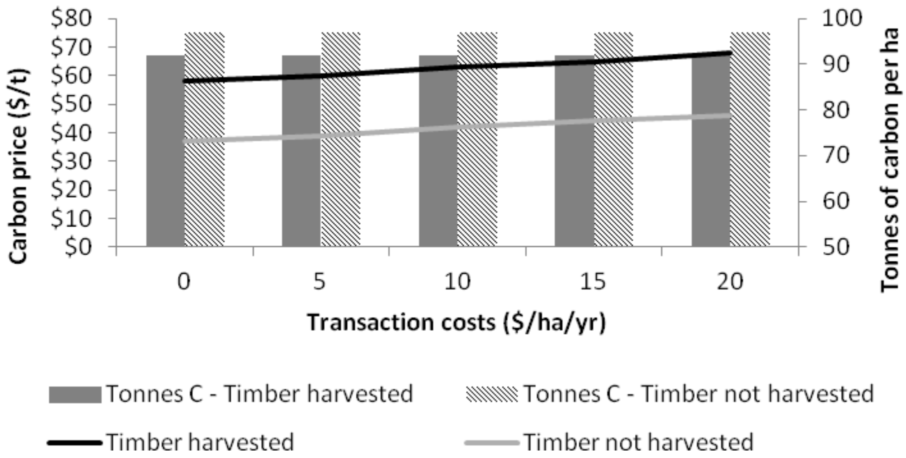

Figure 4 Effect of transaction costs on minimum carbon price

Wood products value

If timber is not harvested and there are no harvest emissions or costs, the carbon price required to induce establishment is significantly lower than if the timber is harvested. As the value of the timber (and pulp) increases the carbon price required to induce participation falls.

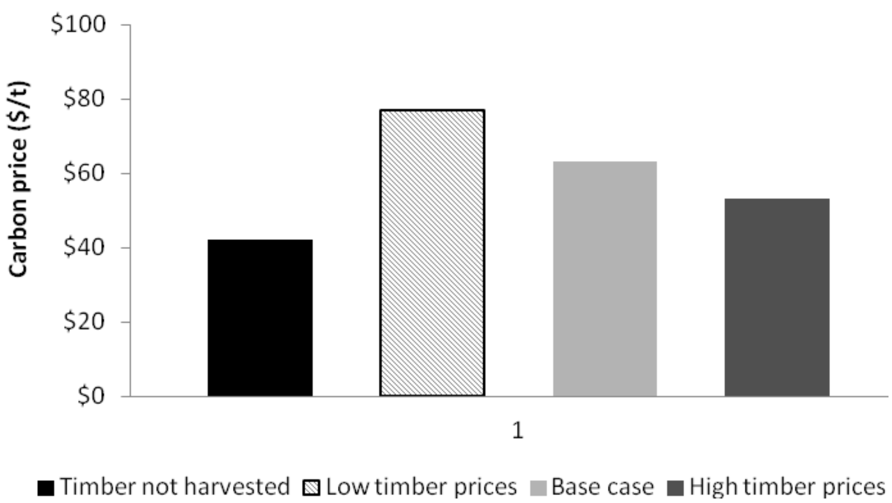

Figure 5 Effect of wood products value on minimum carbon price

Opportunity cost of grazing land

An increase or decrease by 50 per cent in the opportunity cost of grazing increases (decreases) the minimum carbon price required by $16 to $20 depending on whether timber is to be harvested or not. This represents a 25 to 40 per cent change in the required carbon price.

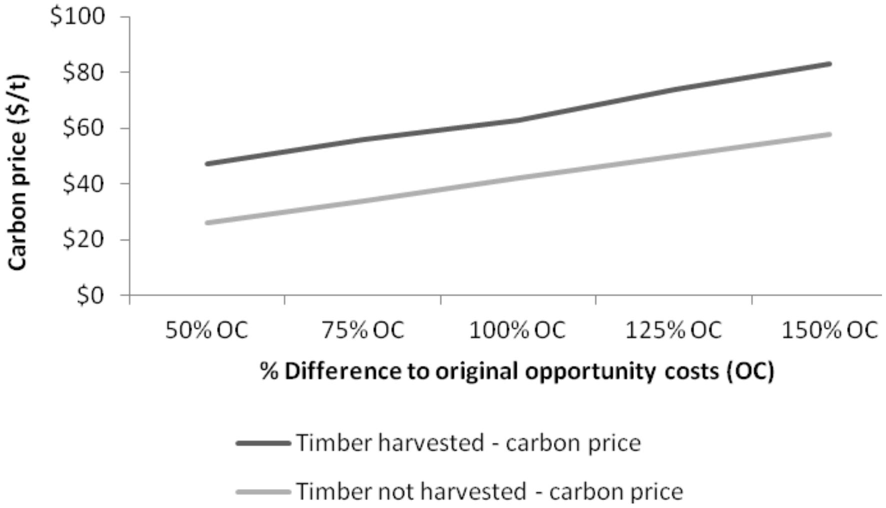

Figure 6 Sensitivity to opportunity cost of cattle

Harvesting emissions

The higher the proportion of carbon emitted at harvest, the higher the minimum required carbon price.

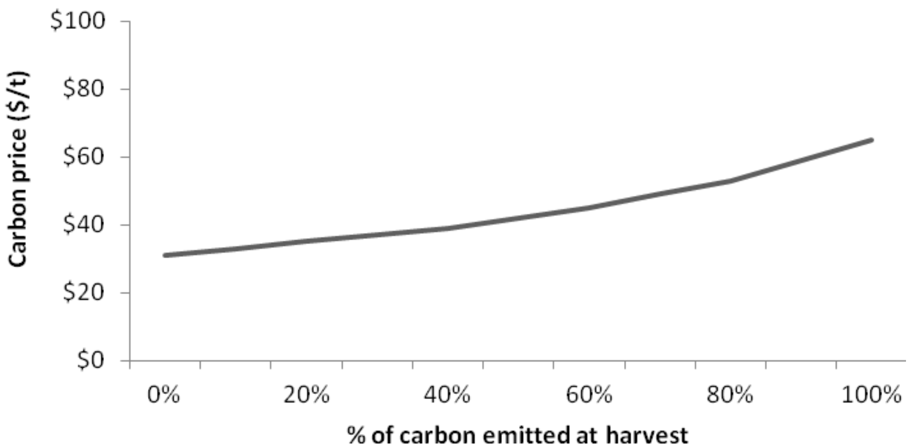

Figure 7 Percent carbon emitted at harvest

Rotational grazing

Due to the number of grazing operations which are already utilising some form of rotational grazing an initial analysis was performed to compare this system to the status quo without any carbon costs or benefits. Using the assumptions as described above, the status quo performs slightly better over a 20 year period (scenario 1) which suggests that some landholders have either found a less expensive way of implementing rotational grazing, are achieving greater than assumed benefits or have some other motivation for using rotational grazing. In the rotational grazing scenario, using the same base assumptions as the forestry option, the status quo grazing enterprise performs better than the rotational grazing option under most conditions. The exception is when the value of cattle (as measured by the land rental rate) is 50 per cent higher than in original analysis. At this point the additional stocking rate achieved by the rotational grazing outweighs the additional costs of this option. Results are shown in Table 4. Sensitivity analysis also shows that if sequestration rates are 20 per cent higher than originally calculated, the difference in NPV between rotational grazing plus carbon trading and the status quo is negligible.

Unlike the forestry scenario, the rotational grazing option does not result in negative NPV even at very low carbon prices. However, the status quo grazing option maintains a higher NPV until carbon prices reach very high levels.

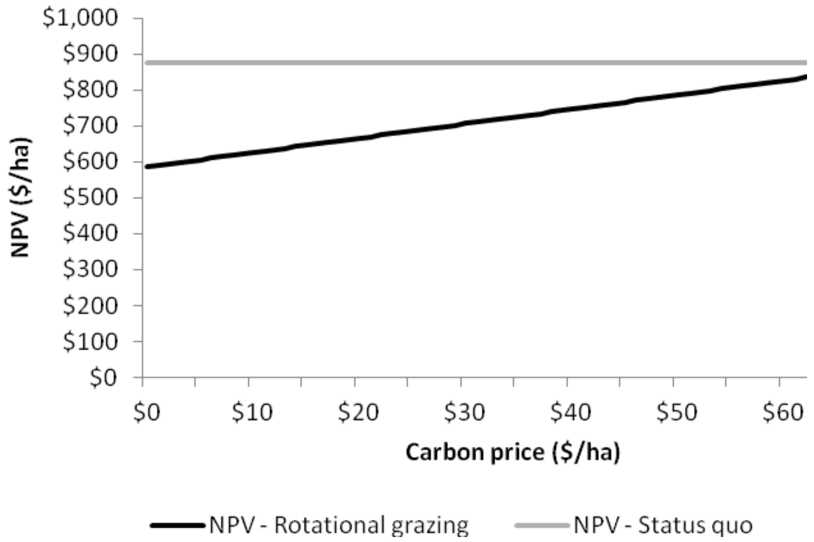

Figure 8 Sensitivity analysis - Rotational grazing

Table 4 Profitability estimates - Rotational grazing

Scenario	**1**	**2**	**3**	**4**	**5**	**6**	**7**
	Rot'l v Status quo - no carbon	Base case	Low Sequestration	High Sequestration	Include methane emissions	Low cattle value	High cattle value
Discount rate	6%	6%	6%	6%	6%	6%	6%
Plot size (ha)	100	100	100	100	100	100	100
Starting year	2011	2011	2011	2011	2011	2011	2011
Cattle value ($/AE)		$127	$127	$127	$127	$64	$191
Include methane emissions (Y/N)	No	No	No	No	Yes	No	No
methane emissions factor (t/AE/yr)	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Rotation length	20	20	20	20	20	20	20
Carbon (t)		660	330	990	-2,011	660	660
Contract establishment costs ($/contact)	$2 000	$2 000	$2 000	$2 000	$2 000	$2 000	$2 000
Annual monitoring costs ($/ha)	$10	$10	$10	$10	$10	$10	$10
Contract length (years)	20	20	20	20	20	20	20
Carbon price ($/t CO2-e)	$15	$15	$15	$15	$15	$15.00	$15
NPV cattle – status quo	$87 539	$87 539	$87 539	$87 539	$87 539	$43 769	$131 308
NPV rotational grazing	$78 475	$84 494	$81 484	$87 503	$60 139	$15 713	$153 274

Optimization results

As was indicated by the results of the price sensitivity analysis, the optimal allocation is to maintain the status quo grazing management unless carbon prices are above $18 per tonne. Although the rates of sequestration are relatively low available the costs of establishing the system are also low and cattle production can be maintained which provides a second income stream.

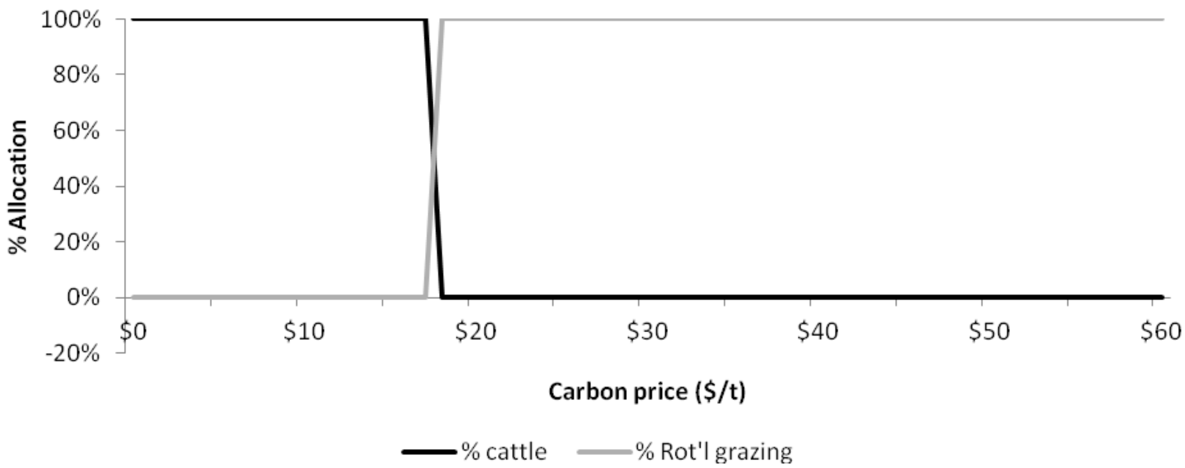

Figure 9 Optimal allocation - Rotational grazing

Transaction costs

The base case as shown in Figure 9 assumes a carbon contract establishment cost of $2000 and an annual cost of $10 per hectare. If transaction costs are zero, the minimum required carbon price falls to $37 per tonne. Only the annual transaction costs impact on the minimum carbon price as increasing the initial cost to $2000 does not change the results.

Although starting at a low minimum carbon price, the rotational grazing option is much more sensitive to increases in transaction costs compared to the forestry options. For the forestry option the minimum carbon price at annual transaction costs of $20 per hectare is 13 per cent higher than the price at $5 per hectare. The same increase in the rotational grazing scenario increases the minimum carbon price by 16 times. These results can be seen in Figure 10.

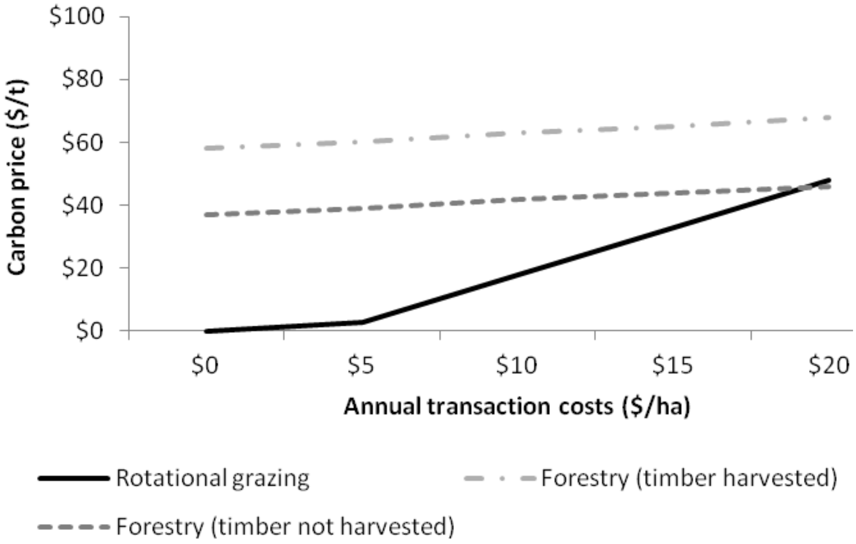

Figure 10 Impact of transaction costs on minimum carbon price

Sequestration confidence

The sequestration estimates for the forestry option are reasonably reliable. However, estimating the net sequestration from switching to rotational grazing is much more difficult and therefore the estimates have much wider confidence intervals. To consider the effect that errors or improvements in measurements would have on results, sensitivity was conducted at 80 through to 120 per cent of the original estimates. The results are shown in Figure 11. As expected, as the sequestration rate increases the minimum required carbon price declines. An increase of 20 per cent on original estimates reduces the minimum price by almost the same amount.

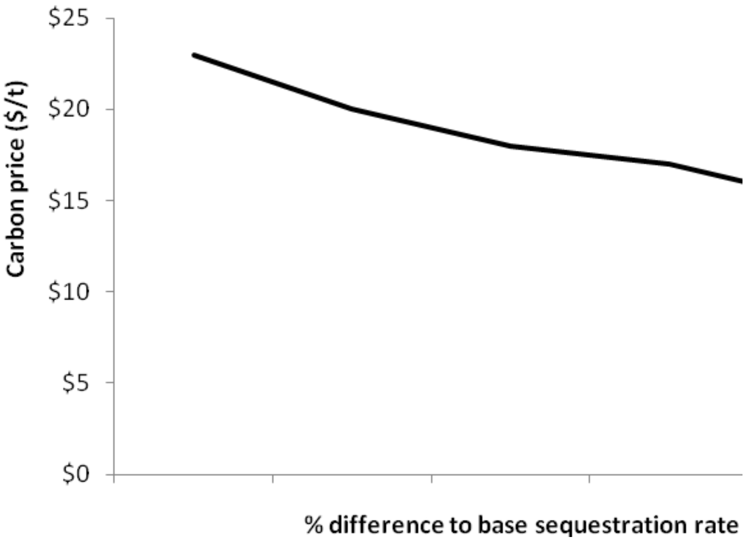

Figure 11 Effect of sequestration rate on minimum carbon price

Maintenance (reseeding) costs

As discussed in the introduction the costs of maintaining the rotational grazing system were found to have a significant effect on the relatively profitability of rotational and status quo grazing systems. Using the base case assumptions for all other variables, the impact of increased maintenance (as measured by reseeding) costs is shown in Figure 12.

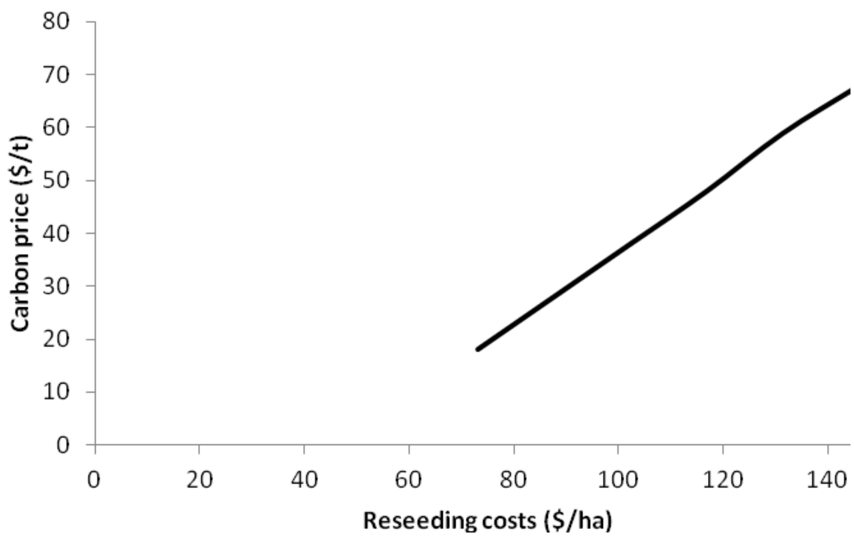

Figure 12 Effect of maintenance (reseeding) costs - Rotational grazing

Discount rates

An interesting result occurs when conducting sensitivity on the chosen discount rate. Private discount rates are generally higher than the public discount rate and include some accounting for risk and uncertainty. Generally increasing the discount rate is expected to lower NPV and reduce the attractiveness of an investment. However, in the forestry option the pattern of costs and benefits results in a different outcome. As shown in Figure 13, the net cash flow in the forestry option is relatively stable, until harvesting occurs in year 20 which results in a large negative cashflow[3], even with the sale of timber. By increasing the discount rate the value of those 'distant' future costs is reduced therefore their impact on NPV is reduced which increases NPV compared to the status quo cattle operation. Therefore, in the forestry option, increasing the discount rate lowers the minimum price required to induce participation (see Figure 14).

The opposite, (but expected) result occurs in the rotation grazing scenario because cash flows are much more consistent over the investment period (see Figure 15– note different scale compared to Figure 13). The result is that the minimum price increases to over $100 per tonne at a discount rate of 20%. The steep decline in cashflows for the rotational grazing system (as shown in Figure 13) are due to the costs of re-seeding the pasture to maintain productivity. .

[3] This graph is based on the base case assumptions including $15 per tonne carbon price. Different carbon prices would result in the same pattern, just a different magnitude.

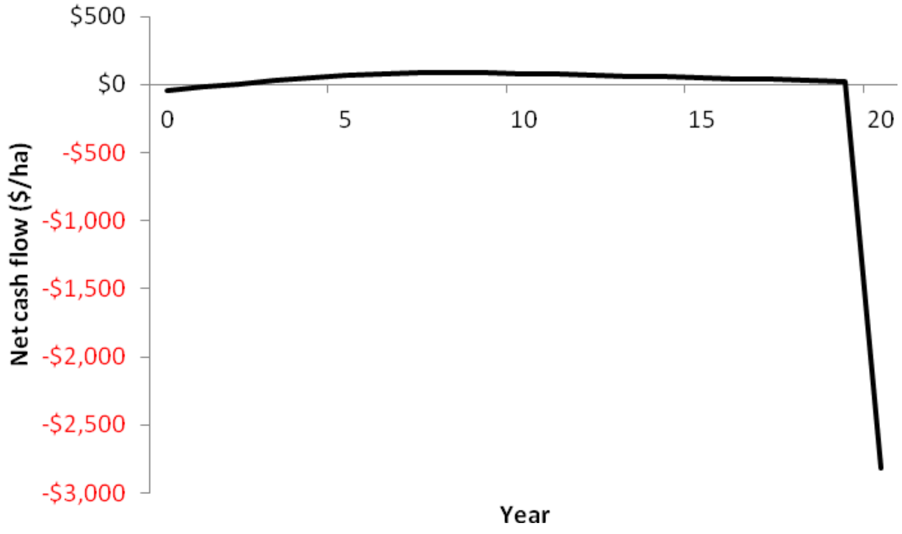

Figure 13 Net cash flow - forestry - undiscounted

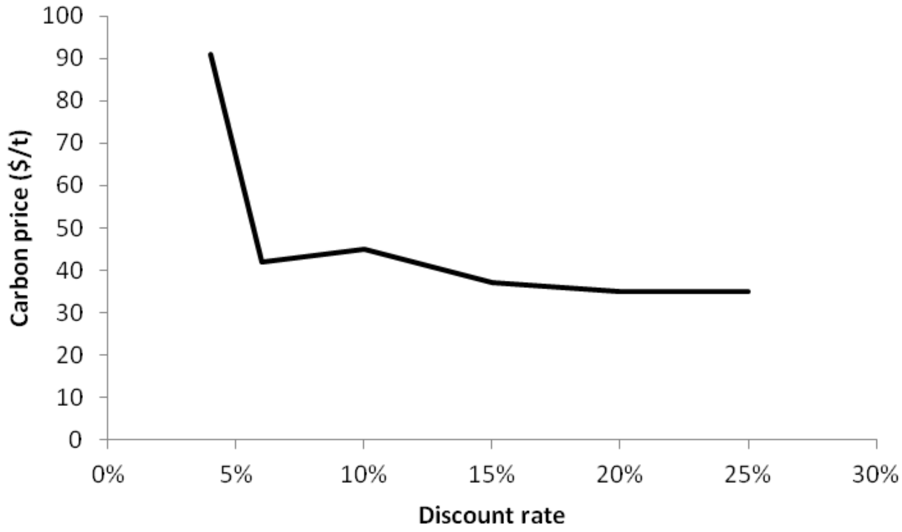

Figure 14 Effect of discount rate on minimum carbon price – forestry

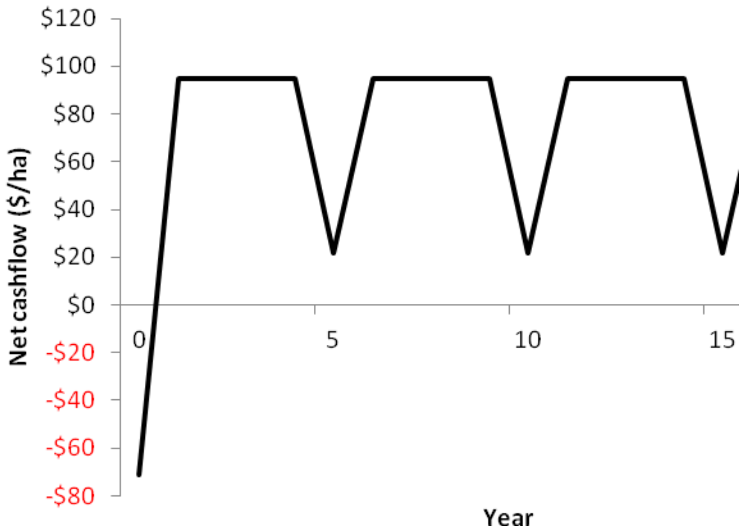

Figure 15 Net cashflow– undiscounted - Rotational grazing

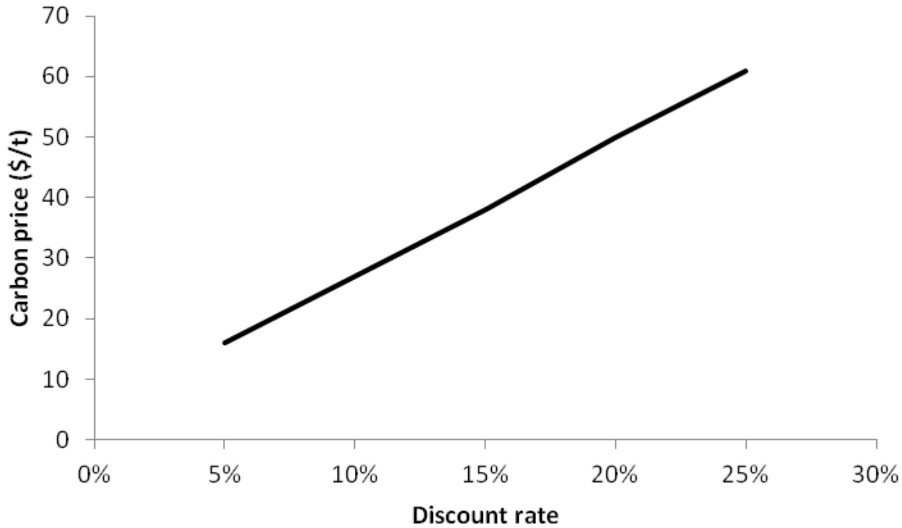

Figure 16 Effect of discount rate on minimum carbon price – Rotational grazing

Discussion

Based on the results of this case study, carbon trading in the Alberta grazing industry is more likely to be implemented as a complementary rather than an alternative enterprise. Similar to previous analyses forestry was shown to be unattractive unless carbon prices are quite high. The minimum carbon prices for the rotational grazing option were much closer to what might be likely if carbon schemes become widely implemented. The results also showed the importance of achieving certainty in a range of factors before accurate estimates of the economic potential supply can be made. In the forestry option the amount of carbon assumed to be emitted at harvest is a major determinant of the relative profitability. This will largely be determined by policy and may differ between jurisdictions, affecting the ability to trade between different markets. Market factors such as the value of wood products and grazing land also impact the profitability of individual sites but values for these are more predictable and less deterministic of relative returns. For potential adopters of rotational grazing as a carbon sequestration practice confidence in measurement protocols and lower transaction costs will have the greatest impact on relative profitability. These will partly be determined by the requirements of trading regulations and partly by technology improvements which may reduce the cost of measurement and verification.

The results contribute to the package of information available to landholders considering the option to trade carbon but highlight the importance of individual analysis to make the final decision. Given that rotational grazing appears to be profitable at low carbon prices it would be expected that all producers who stand to benefit would switch practices immediately. However, the model is based completely on expectations of rational utility and does not include the behavioural responses of landholders. Depending on perceptions of risk and uncertainty, preferences for autonomy and non-monetary motivations for land management choice, a much higher minimum carbon price may be demanded before landholders are willing to participate.

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