Soil carbon sequestration in mixed farming landscapes: Insights from the Lachlan Soil Carbon Project

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Abstract

The potential for soil carbon sequestration to play a significant role in meeting Australia's greenhouse reduction targets has attracted widespread interest. Despite this interest, the economic scope for soil carbon sequestration remains poorly understood and the practical approaches that could be used to capture any opportunities have not been explored. In this paper we present preliminary results on a pilot soil carbon sequestration variable price, reverse tender auction in the mixed (wheat-sheep) farming system of the Lachlan Catchment, NSW. We draw on the results of the pilot to reveal; contract choice, landholders costs of soil carbon sequestration and the extent and impact of transaction costs associated with basic cost-effectiveness of the market mechanism.

Keywords

Contract choice, transaction costs, MBI

1. Introduction

The Australian Government has committed to reduce Green House Gas (GHG) Emissions. Two targets have been set to reduce carbon (t CO2e) from the 2000 base year, a reduction of 5% by 2020 and a reduction of 80% by 2050 (Australian Government, 2011). To achieve these reductions, the government is undertaking a range of initiatives, the most significant of which is explicitly placing a price on GHG emissions. This was initially implemented in July, 2012 by placing a fixed price on carbon emissions (ie. a carbon tax) of $23/ tCO2e for the largest producers (e.g. stationary energy sector, transport, industrial processes non-legacy waste and fugitive emissions). From 2015 the carbon price will become variable and will be set by the market through the establishment of an Emissions Trading Scheme (*Clean Energy Legislation Amendment Act 2012*).

The agricultural and land sectors have been excluded from coverage under a carbon price. As a consequence, there are no requirements for landholders to formally account and pay for emissions related to agricultural production. This stance is consistent with widely acknowledged difficulties for sector inclusion that has been discussed at length in the current Garnaut Review (Garnuat 2008) as well as previous reviews of emissions trading in Australia. Recent policy developments do however offer opportunities for landholders to derive benefits from either reducing emissions or storing carbon. However further research is needed to determine the cost-effectiveness of each agricultural commodity in achieving the national targets (Garnuat, 2008). This paper describes one such research project, a soil carbon sequestration Market Based Instrument (MBI) pilot and reports preliminary results about the likely cost effectiveness of soil carbon sequestration.

The current legislation enables agricultural carbon offsets via emissions avoidance and sequestration through the Carbon Farming Initiative (CFI). The CFI allows agricultural activities that are Kyoto compliant (e.g. reforestation and savannah fire management) to gain

Australian Carbon Credit Units (ACCU) which can be used by sectors to offset their own obligations under carbon pricing arrangements[1]. Additionally CFI provides incentives for non-Kyoto compliant activities, e.g. biochar and soil carbon sequestration to gain Non-Kyoto ACCUs which can be bought by government through the CFI Non-Kyoto carbon fund or a voluntary market (*Carbon Credits (Carbon Farming Initiative) Act 2011* passed May 2012). The economic benefit of introducing offset policies like the CFI is determined directly by the difference in marginal abatement costs in the sectors with (the purchaser) and without (the supplier) carbon obligations.

The potential for soil carbon sequestration in particular, to play a significant role in meeting Australia's greenhouse reduction targets, has attracted widespread interest amongst farming groups, scientists and policy makers. The Federal opposition has soil carbon sequestration as a centrepiece of its "Emission Reduction Fund". A total of 140mt of CO2-e reduction is proposed to be achieved through the fund, of which 85mt (61 per cent) is associated with soil carbon sequestration. The opposition's policy notes that "the single largest opportunity for CO2-e emissions reduction in Australia is through bio-sequestration in general, and in particular, the replenishment of our soil carbons. It is also the lowest cost CO2-e emissions reduction available in Australia on a large scale. Significantly improving soil carbons also helps soil quality, farm productivity and water efficiency, and should be a national goal regardless of the CO2-e abatement benefits" (Coalition Direct Action on the Environment and Climate Change – policy statement, February 2010).

Soil carbon sequestration requires that the total amount of soil organic carbon (SOC) is increased above its current level and that the increase is maintained into the future. The typical pathway for sequestration of atmospheric carbon in soils involves the capture of carbon dioxide (CO2) by plants through photosynthesis, followed by a deposition of captured carbon into or onto soil. For carbon to be sequestered in soil, the rate of carbon addition must be greater than the rate of carbon loss (CSIRO 2009). Increases in soil carbon can be achieved through the adoption of alternative land uses and/or land management practices that either increase biomass inputs into the system or reduce losses out of the system. Typically they include the adoption of conservation tillage practices, greater retention of crop residues, changes in land use towards perennial production systems and improved pasture management.

Estimates for soil carbon sequestration vary considerably between sources and over time. Globally the conversion of land to agricultural practices has typically resulted in decreases in SOC in the order of 40 to 60% from pre-clearing levels – this represents emissions of at least 150 Pentagrams of carbon dioxide to the atmosphere (Sanderman et al., 2010). According to the latest IPCC estimates, soil carbon sequestration globally can contribute to 89% of the total technical mitigation potential for agriculture (Smith *et al.* 2007). This potential is particularly recognised in countries where large tracts of land are under agricultural practices, e.g. USA, Australia, Canada, Brazil, etc. Australia has identified a large potential in soil carbon sequestration with estimates ranging from 25 to 68 MtCo2e annually (Eady, et al., 2010).

A key issue for policy makers is how to convert technical soil carbon sequestration potential into actual long term carbon storage (sequestration) and hence include soil carbon sequestration into national mitigation efforts. In 2010 the NSW Department of Primary Industries and the NSW Department of Environment, Climate Change and Water (DECCW)

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[1] *Note that in the fixed price period, parties with carbon obligations can meet only up to 5 per cent of their responsibilities using CFI credits.*

were funded to design and test a market based instrument (MBI) to support landholders adopt practices that increase soil carbon. The pilot project is being implemented in central west NSW in cooperation with the Lachlan Catchment Management Authority. In this paper we describe the MBI pilot and report preliminary results about the likely cost effectiveness of soil carbon sequestration.

The paper is organised as follows. In the next section, we review the rationale for including agricultural offsets, like soil carbon sequestration, into national mitigation efforts and outline why markets are likely to be preferable approach to achieving outcomes and the efforts-to-date internationally to include soil carbon sequestration in carbon markets. Section 3 then provides a description of the MBI pilot, including the challenges encountered in designing the market, in the Lachlan Catchment in NSW. Some preliminary results on the cost effectiveness of soil carbon sequestration are provide in Section 4, followed by a discussion and concluding remarks in Section 5.

2. Markets for soil carbon sequestration

Private benefits and costs of sequestration

In the absence of a market for soil carbon sequestration, the private benefits and costs of soil carbon sequestration will determine farmers' decisions about land use and land management practices. Profit maximising farmers will expand soil carbon sequestration activities up to the point where the price received for the last unit of sequestration produced is equal to the additional cost incurred in producing that unit. In economic terms, this is the point where marginal private benefits equal marginal private costs. Departure away from this point is sub optimal because either marginal benefits are foregone or excess marginal costs are incurred. With long lags in the accumulation of soil carbon, the marginal benefits and costs of sequestration reflect production values over an extended period of time.

The benefits of soil carbon are well known. Sanderman et al (2010) summarise these as; improvements in soil structure, soil fertility, nutrient retention, water holding capacity, and reduced soil erosion. Dalal and Chan (2001) showed that higher soil organic matter allows water and air to move more easily through the soil resulting in higher infiltration rates and improvements in water holding capacity of the soil. Improvements in the physical properties of soils, related to higher soil carbon levels, can translate into higher productivity through improved crop yields and reduced inputs of fertilizers, pesticides and water (Lal 2004).

The private costs associated with soil carbon sequestration include the opportunity cost of giving up the net returns from the existing land management practices together with the switching cost to the new land management practice. We refer to these as sequestration costs (S_t) defined as the net present value of revenues from the proposed land management practice ($R_{P,t}$) minus the net present value of revenues from the current land practice ($R_{C,t}$) plus any costs associated with changing from the current to the proposed practice ($K_{\mathrm{C\text{-}P,t}}$), all over period *t*.

$$S_t = R_{P,t} - R_{C,t} + K_{C\text{-}P,t} \qquad \text{(E1)}$$

Public benefits and costs of Soil Carbon Sequestration

There are two types of costs associated with SOC sequestration in an MBI, first abatement costs, or the previously defined private sequestration costs (S_t) those costs associated with producing one unit of SOC carbon. It is this abatement cost which should be reflected in the bid prices provided by farmers. Of course it is known that increasing SOC provides benefits directly to the farmer, including improved soil quality, improved productivity, improved water use efficiency, resulting in increased yield and hence revenue generation capacity. Therefore these 'private benefits' do not need to be paid for in an MBI as they are already providing benefit to the farmer, as such for any SOC sequestration improvement it is assumed that the net present value of revenues from the proposed land management practices ($R_{P,t}$) includes the increased private benefit from more SOC.

The second type of costs associated with SOC sequestration are transaction costs and are associated with the costs of contracting *ex ante* and *ex post* the contract signing. Transaction costs correspond with activities undertaken in the process of achieving an agreement and then continuing to coordinate implementation of the agreement respectively. They are borne by both buyers and sellers in the contract. Table 1 provides a categorisation of transaction costs associated with soil carbon sequestration; it is based on previous work by Cacho and Lipper, 2006, McCain et al., 2005, Challen 2000; Falconer and Whitby 1999 and Falconer et al 2001. Four transaction cost categories are found throughout the project implementation with the first two *ex ante* and the last two *ex post* contract signing. Each cost can either be fixed, ie. it's a one off cost per site associated with SOC sequestration through the pilot or is variable by site size.

Table 1. Categorisation of transaction costs for soil carbon sequestration project as related to buyers and seller of soil carbon. Where FC are fixed costs and are per site, while VC is variable costs that change depending on the size of the site.

Cost type	Buyer	Seller
Search and negotiation	W_S	w_S
	• Design project (FC) • Advertising and workshops (FC)	• Attend information sessions (FC) • Design landholder actions and costs (FC)
Project Development	W_D	w_D
	• Establish software and payment programs (FC) • Undertake site visits (VC) • Undertake initial soil C sampling and analysis (VC)	• Attend inital site visits (VC) • Fill in bid form (FC)
Project management	W_P	w_P
	• Maintain database and administer payments (FC) • Coordinate landholder responses (FC)	• Read regular project emails and information (FC)
Monitoring & enforcement	W_E	w_E
	• Calculate payments (FC) • Process and coordinate soil C samples (VC) • Undertake audits (VC) • Settle disputes (FC)	• Annual reporting forms filled (FC) • Protect site from external influences (VC)

Therefore an estimate of transaction costs experienced by buyers (L_t) and sellers (l_t) is a simple addition of component costs.

$$L_t = W_S + W_D + W_P + W_{En} \tag{E2}$$

$$l_t = w_S + w_D + w_P + w_E \tag{E3}$$

For landholders to participate in the pilot project the transaction costs (l_t) must be equal to or less than the perceived sequestration costs (S_t) (which includes all private benefits) of undertaking the new project plus any payments received (P_t).

$$l_t \leq S_t + P_t \tag{E4}$$

Whilst for sellers to participate in the pilot project it must satisfy two criteria. First, to be effective in SOC sequestration, i.e. that sellers transaction costs (Lt) are less than the total payments made for all landholder *j* (1…n).

$$\sum_{j=1}^{n} P_{i,t} \geq L_t \tag{E5}$$

Second, that the cost efficiency of SOC sequestration in a broader carbon sequestration market is only viable until marginal SOC sequestration (ie. total seller transaction costs and payments divided by tonnes of Co2e sequestered (T_{SOC})) is at least equal to marginal carbon sequestration or abatement in any other competitive industry (where total costs and payments for industry *I* is TP_I and total CO2e abated or stored is industry *I* is T_I

$$(L_t + \sum_{j=1}^{n} P_{i,t})/\, T_{SOC} \leq TP_I/\, T_I \tag{E6}$$

The introduction of a soil carbon market provides additional incentives for farmers to sequester carbon. The additional payment relating to the value of the carbon, results in an increase in the optimal level of sequestration, the extent of which depends on the elasticity of supply.

All other things equal, with a market in place, the farmer now faces benefits derived on-farm in the form of marginal private benefits (S_t), and a separate Profit maximising producers, faced with the additional payment for sequestration, will expand their level of sequestration accordingly. Soil carbon sequestration, subject to appropriate monitoring, verifying and reporting standards, can be included in any carbon abatement schemes.

Soil carbon markets

Globally SOC has been ‘traded’ in one regulated and two voluntary schemes. Alberta is the only jurisdiction known, with legislated requirements for GHG emissions reductions which include a SOC offset capacity. Around 3.2 million tonnes (MT) of CO2e, or 15 per cent of required emission reduction, has been achieved since 2007. This has generated close to \$38 million of new wealth for agriculture in Alberta (www.carbonoffsetsolutions.ca).

Voluntary offset registers are also in operation for SOC through Chicago Carbon Exchange Offsets 2011 (previously Chicago Climate Exchange 2003-2010 traded SOC credits) and the Voluntary Carbon Scheme. While both these registers of offsets can support market based mechanisms (e.g. offsetting), their focus is on providing trusted, robust and user-friendly systems. They bring quality assurance to voluntary carbon markets and providing innovative rules and tools for businesses, non-profits and government entities to engage in on-the-ground climate action.

Soil carbon sequestration needs to be economically competitive with other options for mitigation if is to form part of Australia's greenhouse response. If all mitigation options meet the same stringent criteria of permanence and additionality, as well as address issues of leakage, options can be rated on their cost effectiveness per tonne of CO2-e alone. Efficiency (cost per tonne of CO2-e to store more SOC) will be the key driver for ensuring that SOC sequestration is part of any future carbon offsetting scheme.

Market based instruments (MBI) have a number of attributes which can make them the most efficient mechanism for producing environmental goods otherwise undersupplied by private prdouction e.g. biodiversity and native vegetation are potentially (Whitten, et al 2004, Grafton, 2005). MBIs introduce economic incentives for access to a natural resource (e.g. water) or the provision of some kind of environmental service (e.g. a change in landholder management practice or an agreed process of revegetation) (Whitten et al., 2004).

There are two main reasons why MBI's might be an appropriate mechanism to increase the supply of SOC. First, MBI's address a form of market failure where landholders, in the absence of government intervention, are unable to capture the full benefits of sequestration. An MBI provides a way to directly reflect the value derived from carbon sequestration and thereby raise the level of sequestration that landholders find privately profitable. Second, there is heterogeneity in those who will be supplying the good. Some farmers will be able to improve SOC sequestration easily and quickly, whilst others it may be more time or resource intensive. This reflects some of the physical factors that influence the rate of SOC sequestration like soil type, rainfall and the type of land management practices and landuses available (Sanderman et al., 2010). It also takes into account that the costs and benefits of implementing particular practices and land uses will vary across farmers.

The main challenge for an MBI targeted at SOC is the high costs associated with implementation, little effort to date has been placed on understanding transaction and production costs with environmental commodity MBIs (Grafton et al., 2005).

3. Methods

The Department of Primary Industries and Office of Environment and Heritage, NSW were provided funding to run a reverse tender auction soil carbon sequestration pilot (similar to BushTender and EcoTender see Eigenraam et al 2007). This section sets out the method for delivering the soil carbon pilot, particularly the process undertaken, type of contract choices and the calculation of soil carbon sequestration.

Process for Pilot

Table 2 outlines the process and timing of implementing the soil carbon pilot project in the Lachlan Catchment Management. Delivery of the pilot was undertaken by Lachlan Catchment Management Authority (LCMA). Importantly to note in September 2011, in the middle of farmers compiling bids and initial site visits the Federal Government released their Clean Energy Future Plan, which included the rates for the Carbon tax.

Table 2. Pilot implementation steps

Implementation steps	Timing
1. General communication with all eligible landholders. 1,580 fliers delivered to all land mangers in the area, Flyer advertised in the three local papers (Canowindra, Manildra and Cudal) for two weeks, discussion on radio stations advertised in websites and local advertorials	March 2011 – Jan 2012
2. Workshops – three half day workshops were held within the Cowra Trough to inform the public and interested participants of the upcoming tender; Canowindra – 4th July, Manildra 5th July and Cudal 18th July, total of 100 land managers attended	July 2011
3. Expression of interest – landholders located in project area register an expression of interest through an LCMA officer ;	July – August 2011
4. Site assessments – the LCMA officer arranges a site visit with each eligible registered landholder. The field officer assess the site(s), undertakes soil sampling on each site, receives a history of each site (past 5 years) and discusses with landholder proposed management actions to be undertaken;	August – September 2011
5. Soil Carbon Expected Score calculated – each site was provided with a SCES and a soil test profile to advise landholders on what soil carbon sequestration was expected at the end of the five years under specific management actions. Federal Government releases Clean Energy Future Policy with carbon price.	September – October 2011
6. Bid development workshop – half day workshop to clarify the process and priorities for submission of a bid and its ranking on 11th October in Cudal, with 30 land managers attending	October 2011
7. Submission of bids – landholders submit a sealed bid that nominates; the type of contract, the amount of payment being sought by them to undertake the agreed management actions, i.e/. Soil Carbon Bid Price in $/ tCO2e.	November 2011
8. Bid Assessment – all bids are assessed objectively on the basis of $/ tCO2e	November 2011
9. Contract - successful bidders are able to sign final agreements based on the previously agreed management actions and contract type (from 6 above)	December 2011
10. Reporting and payments – payments and reporting occur as specified in the agreement.	January 2012- 2017

For farmers to be engaged in the pilot there were strict eligibility criteria:

- *Property*; within Cowra Trough (see Figure 1), freehold land, clear and established ownership, minim property size, maximum bid size 2,000 tCO2e, with dominant soil type non-calcic brown soil.
- *Site*; maximum number of 3 sites per entity, minimum bid amount 70 tCO2e, maximum sequestration rate 3.7 TCO2e/ ha, no other payment schemes aligned to site.
- *Landholder*; has capacity to implement the agreed actions and is independent of the pilot implementation process.

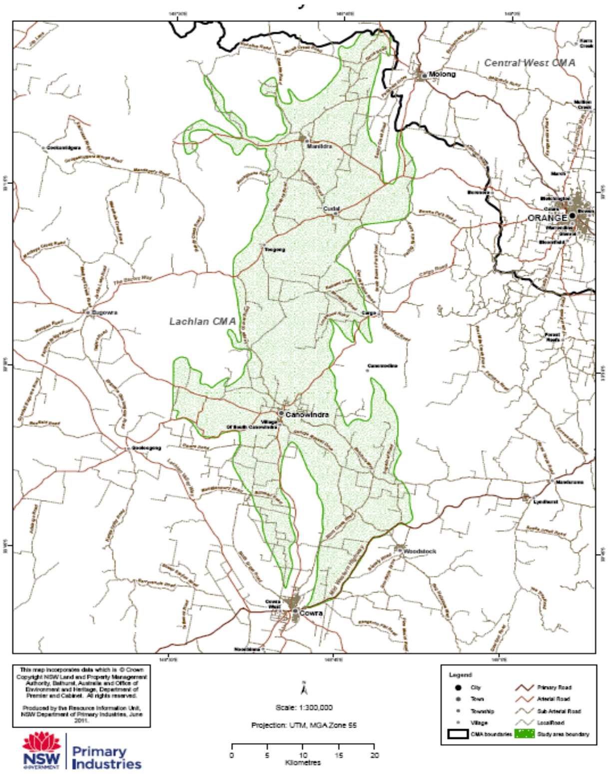

Figure 1. Map of Cowra Trough

Contract choices and eligible actions

The contract was between a farmer entity (proponent) and the Lachlan Catchment Management Authority (LCMA) and be for a term of 5 years. The CMA will contract the farmer to sequester soil carbon on their property based around an expected rate. The soil carbon stored in the 5 year contracted period will be 'owned' by the LCMA for the contract period. Once the contract has ceased, all carbon will revert to landholder ownership. The LCMA will not 'on-sell' or trade the carbon within the contract period.

The proponent has a choice of three possible contracts (Table 3); **Actions-based contract** – farmers are paid to undertake standardised management actions that will enhance soil carbon; **Outcome-based contract** – farmers are paid on the actual change in soil carbon levels of eligible landholder-defined actions see Table 3 (based on contract signing and final soil tests in years 1 and 5); and **Hybrid contract** – farmers are paid 50% for adopting either conservation tillage or permanent pasture standardised management actions and 50% for the actual change in soil carbon levels (based on contract signing and final soil tests in years 1 and 5).

Table 3. Eligible Land uses by contract type

Land uses	Actions-based Contract requirements	Outcomes-based contract requirements
Cropping	○ Conversation to Conservation Tillage (may include pasture phase) • Retain stubble • Achieve less than 20% surface disturbance pre and during sowing • If in pasture phase then requirements include those identified with the 'permanent pasture – tactical grazing' action	○ Changing to a cropping systems that sequester more soil carbon, including; • Decreased tillage • Increased stubble retention ○ NOT eligible actions include: • Establishment of weed species • Changing to a farming regime that decreases soil carbon sequestration
Pasture	○ Conversation to Permanent Pasture – Tactical Grazing • Sow perennial grass dominant pasture • Attain at least a 1 tonne /ha herbage mass, all year by removing pasture • At least 70% ground cover in March/ April • Attain > 30% perennials in September /October	○ Changing to a permanent pasture systems that sequester more soil carbon, including; • Increased soil fertility • Increased perenniality in pasture • Increased biomass production in pasture ○ NOT eligible actions include: • Adding organic soil ameliorants in years 3,4 and 5, e.g. organic compost or biosolids • Establishment of weed species • Changing to a farming regime that decreases soil carbon sequestration
Environmental Plantings	○ Environmental Plantings • Attain 20% canopy cover at 5 years of planted native vegetation with significant woody plant cover • Attain > 70% on the ground surface to achieve a large litter component	○ NOT eligible

Soil Carbon Calculator

A landholder's bid is ranked according to a $/ tCO2e soil organic carbon sequestered via specified landholder actions. The pilot has focussed on assessing existing soil carbon levels (initial 5 years) under different combinations of land management, climate and soil landscapes within the Lachlan catchment (see Murphy et al., 2012 for elaboration). This has required wide scale soil sampling, and extensive analysis of soil samples. By defining the soil type, climate, and land management practices applied to the soil it is possible to predict the expected levels of soil carbon for a particular paddock. The soil carbon levels predicted in the pilot are estimated by the Soil Carbon Calculator. The calculator is published in Murphy et al (2012) and is based on the best available scientific knowledge available on the potential and likely rates of soil carbon sequestration with specific environmental conditions on specific soil types and under different land holder defined actions and land uses.

The Soil Carbon Expected Score (SCES) is based on the initial starting level of the soil organic carbon store ($¢_I$) and the expected final long term equilibrium level of the soil organic carbon store under the contracted land management system ($¢_E$). It is this difference between the initial level and the final level which is important in predicting the potential for soil carbon sequestration.

The next requirement is to normalise or calibrate this estimate to the local region to account for the local climate, soil types and climate. This can be achieved by estimating the following:

- The maximum change in soil organic carbon (SOC) level that can be expected from the land management system with the lowest SOC levels to the highest soil carbon levels in an agricultural land use ($¢_{max}$). For the Cowra Trough Red Soils this was estimated at 38 t/ha/30 cm for minimum tillage, 44 t/ha/30 cm for permanent pasture and 70 t/ha/30 for environmental plantings.

- The maximum rate of change of SOC that can be expected based on the local climate and soils and so the potential biomass growth for a region (s_{max}). This was estimated at about 1000 kg/ha/30 cm/yr based on published information.

The predicted initial rate of change (first 5 years) of SOC stores ($\hat{s}$) was given by the equation below:

$$\hat{S} \text{ (t/ha/30cm/yr)} = s_{max} * (¢_E - ¢_I) \,/\, ¢_{max} \qquad \text{(E7)}$$

Note that this equation assumes that a linear relationship for estimating the rate of change of soil carbon and this assumption is only a valid approximation for the first 5 years. After 5 years the rate of change in soil carbon will no longer be a linear a relationship and the rate of change in soil carbon will vary with time.

The Soil Carbon Expected Score (SCES) for any bid is then estimated by converting the SOC rate of change ($\hat{s}$) to CO2e (standard conversion factor of 3.6667) and determining the area per bid (is multiplying it by ha).

By establishing a pilot which enabled farmers to choose the type of contract preferred, the research was able to test a number of different issues. There are few studies that test the actual effectiveness and costs associated with the delivery of different contract types – most studies assume that farmers will be paid to provide a desired outcome; the actual implementation is not seen as significant.

4. Preliminary Results

A summary of participation in the discretionary price reverse tender auction of soil carbon is found in Figure 2. A total of 26 bids were received covering all three types of land management practices and employing all three types of contract options. Importantly the majority of bids 17, relate to land management changes (10 within permanent pasture, 7 within cropping) with only 9 bids related to land use change either to permanent pasture (6 bids), cropping (1 bid) or environmental plantings (2 bids).

	Site Assessments	Bids
Entity Participation (no.)	23	18
Sites assessed (no.)	32	26
Area of sites (ha)		1,772.6
Total tCO2e		11,455

Land management regime	% of total carbon	Total No. of bids	Total Carbon	Type of contract
Permanent Pasture	54%	16	6,157.61	Actions -2; Outcomes – 8; Hybrid – 1
Conservation Cropping	45%	8	5,153.75	Actions -1; Outcomes –7
Environmental Plantings	1%	2	144.08	Actions -2

Figure 2. Summary statistics of participation in the reverse tender soil carbon auction.

Benefits of soil carbon sequestration

The private sequestration cost (St) or abatement cost for the suppliers to deliver soil carbon is found in Figure 3. This illustrates the cost of generating additional units of soil carbon. The horizontal axis depicts the total quantity of soil carbon expected to be supplied where bids are assembled in ascending price order. With the vertical axis displaying the increasing price for each additional unit of carbon.

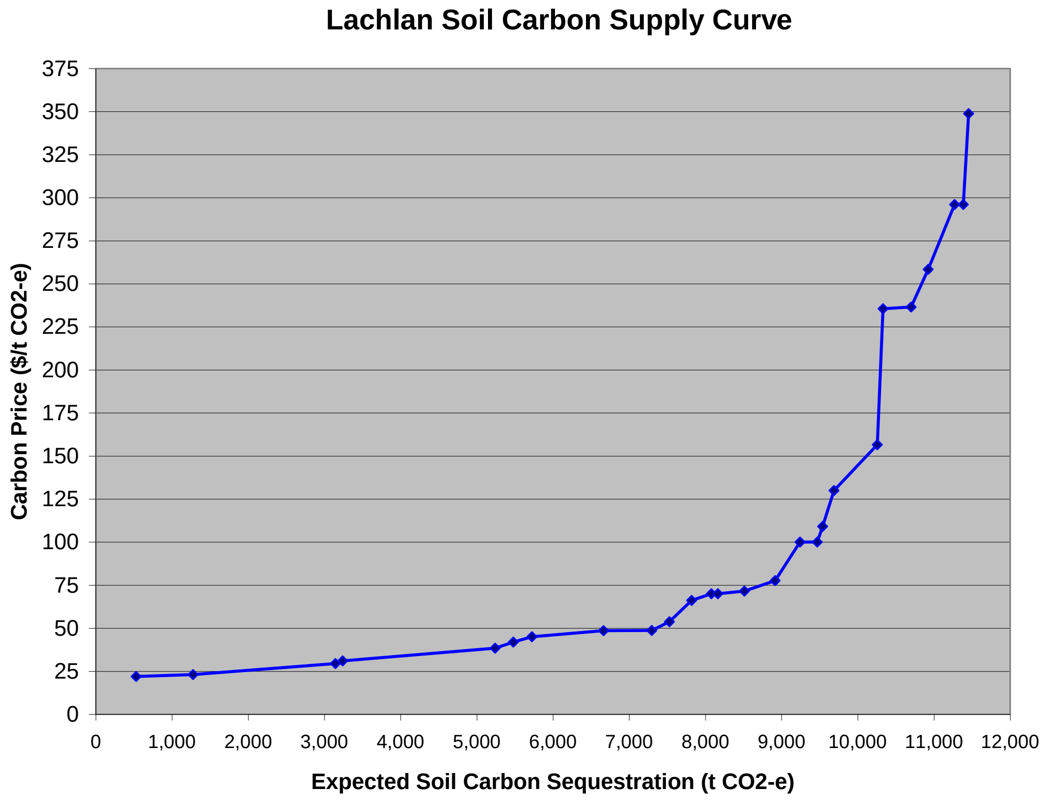

Figure 3. Marginal cost curve for expected soil carbon sequestration

As indicated by Figure 3 soil carbon sequestration follows a theoretical supply curve functional form (upwards sloping). There are large horizontal gaps between the data points at lower end of the curve, indicating that there is potentially economies of scale in the production of soil carbon at lower prices (i.e. $ per t CO2e). Conversely the bids costing higher amount (larger $/ t CO2e) secure only small amounts of carbon (i.e. they are closely spaced along the horizontal axis).

Analysis of costs

Due to the lack of variety in participation of contract types we have chosen to estimate costs on the basis of outcomes based contracts. Estimates of costs were gathered from LCMA and discussions with farmers, results are presented in Table 4.

Table 4. Transaction cost table for outcome based contracts for buyers and sellers where contracts are per 100ha site for the five year contract. Costs are split into FC, fixed costs, that do not vary by size and VC, variable costs which are at a rate of per site up to 100ha then pro rated for every 10ha over the 100ha baseline.

Cost type	Buyer	Seller
Search and negotiation	FC W_S = $21,600	FC w_S =$2,000
Project Development	FC W_D= $33,500	FC w_D= $2,000 VC w_D= $500 per site + $486 per site then

		pro rata by 10%
Project management	FC W_P = \$3,000	FC w_P=\$1,250
Monitoring & enforcement	FC W_E= \$26,500 VC W_E= \$250 per site	FC w_E=\$500 VC w_E=\$1,000 per site + \$1,342 pro rata

To clarify the potential impact of these transaction costs in a soil carbon sequestration project we can estimate their magnitude per area and per t CO2e (Table 5). As shown the higher transaction costs are born by the seller, primarily related to costs associated with three soil carbon tests per site.

Table 5. Relative magnitude of transaction costs for the soil carbon pilot project in Lachlan

	Pilot results		
	Buyer (L_t)	Seller (l_t)	Total (L_T + l_t)
TC \$/ ha	\$57.53	\$124.42	\$181.95
TC \$/ t CO2e	\$8.90	\$19.25	\$28.16

Pilot Soil Carbon Market Characteristics

In section 2 we outlined three basic functional requirements necessary for a soil carbon market to be viable (E4, E5 and E6). The first is to determine if private landholders would participate in the market, by incorporating transaction costs into their decision process (E4). Due to the market structure used in the pilot, a discretionary price single bid reverse tender auction, there are two ways of interpreting the results. First, the payment received (P_t) is equal to the private costs for soil carbon sequestration (ie. $S_t = P_t$). Alternatively, as it is a one-shot single bid reverse tender, we could hypothesise that the farmers would be willing to undertake the expected increase in SOC already, and the payment (P_t) is to cover inclusion in the pilot market (transaction costs of l_t) or a rent seeking behaviour. Therefore unless the private cost represented in the 'bid ask' incorporates some of the transaction costs associated with engagement in the pilot, there should be little reason for landholders to be involved in the pilot, as they will always be bearing some private transaction costs.

From the seller's perspective, an effective soil carbon sequestration occurs when the total seller's transaction costs are less than the total payments made to all the landholders (found in E5). The analyiss is easily done on a t CO2e basis by comparing results in Table 5 with those in Figure 3 to show that at no point was the sellers transction costs higher than the acutal payments made to landhodlers. However, it is not as clear when udnertaking the anlayiss from an spatial perspective, Figure 4, shows the transaction costs for the seller were higher than the two lowest bid options when considered in average area terms. However in total, under both scenarios transaction costs were lower than the total payments to landholders.

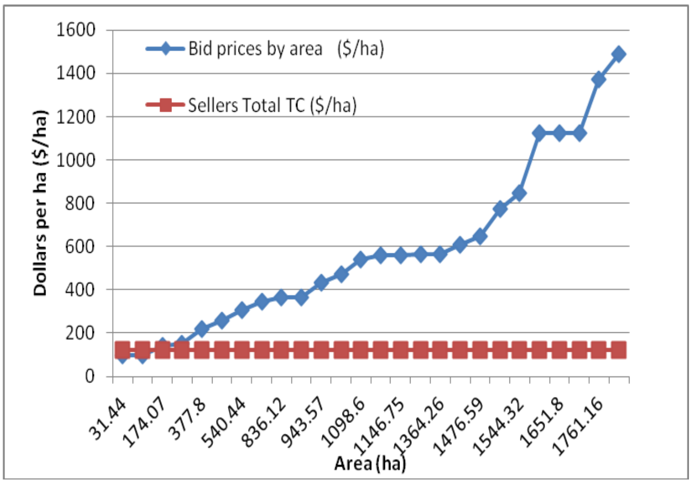

Figure 4. Bid prices by area of land udner contract and sellers transaction cost per area ($/ ha).

The second area where cost efficiency of the pilot project is tested, is in relation to the broader carbon market, to ensure that SOC market viability is only up until the marginal SOC sequestration is at least equal to marginal carbon sequestration or abatement in any other compeittive industry (E6). Whilst there is currently no viable soil carbon sequestration market, Australian current legislation has a carbon tax of $23/ t Co2e, soil carbon sequestration is not viable as an offest to this tax as it is non-Kyoto compliant. The basic analyis from Figure 3shows that there is only one bid which would be competitive in this (tax) market, not accounting for the transaction costs from the buyer or seller. Therefore, pilot results indicate that SOC is not a viable entrant in the CO2 market, as it is cheaper to buy T CO2e from other inudstries.

Characteristics of successful bidders

Understanding the characteristics of the successful tenders in the soil carbon project is critical to knowing how applicable the results are to other parts of Australia. Due to the low numbers of participants it is not possible to undertake any statistical analysis of the results; however we can gain some generalisable insights around risk profile of farmers and economies of scale of sites.

During the initial site visit farmers were asked three questions to gauge their risk profile with respect to farming, confidence of farmers to influence soil carbon sequestration and the soil carbon pilot methodology. Each answer was ranked 1 to 9, with 1=no, 5=neutral, 9= very much. Whilst not statistically analysed (due to low numbers) some general findings can be made and overall averages and spreads are reported in Table 6.

Table 6. Basic risk profile of the farmers entering bids in the soil carbon pilot.

	1. You are willing to take risks in your agricultural production decisions in order to achieve the best results	2. You believe that good management can have a large influence on soil carbon sequestration	3. You consider that the soil carbon model used in the pilot can accurately estimate carbon sequestration on your land
Mean of all responses	7	7.6	6.6

Mean of only successful farmers	5	7	5
Mean of only unsuccessful farmers	8	8	7
Spread of all responses	3 to 9	7 to 9	2 to 8

The results show that overall the farmers are risk taking (ie. means above 5 for Question 1) though those that were successful were more neutral than those unsuccessful in the bidding process. Additionally all the farmers believed that they could have a large influence on the amount and rate of soil carbon sequestration (mean of 7.6) which reflects the true desire for farmers to be engaged in the pilot. Additionally the issue the farmers had the least confidence in was the soil carbon model used in the pilot (mean of 6.6 and spread 2 to 8), this is further exemplified when considering that most farmers opted for the outcomes contract (i.e. paid on actual SOC sequestration not on the soil carbon calculators results) and noticeably those farmers with low (i.e. <5) confidence in the calculator opted of the outcome or hybrid contracts.

During the bid submission process framers were asked about the size of property on which each bid was located. This information was analysed to understand if any ‘economies of scale’ were probable in SOC sequestration during the pilot. To gather this data had to be cleaned, to ensure each property size was only calculated once, no matter how many bids were submitted and when analysed by success or unsuccessful bid the farmers that were both categories had to be excluded. Therefore basic results are presented below in Table 7.

Table 7. The mean site and property size for all bids and farmers by their success in the pilot

	Sites (ha)		Properties (ha)	
SITES	Mean	Spread	Mean	Spread
Successful group	68	17 to 136	771	200 to 1334
Unsuccessful group mean	68	11 to 243	750	116 to 1,827
FARMERS				
Successful group mean	70	23 to 136	862	200 to 1334
Unsuccessful group mean	66	14 to 122	723	116 to 1,827

5. Discussion

The results have raised a number of issues which, whilst not resolved in this paper, are posed for further testing and consideration in design for further soil carbon sequestration schemes.

First we have found a preference for outcomes based contract types. These contract types provide greatest flexibility to the farmer (with respect to timing of activities, which activities and total amount of sequestration achieved), whilst still securing an ‘expected’ sequestration total for buyers. Outcomes based contracts do however poses high transaction costs and do not rely on high trust in government models, i.e. perceived as lower risk to farmers.

Second, transaction costs were very high due to the need for 3 soil tests. This is a high number of soil tests but it is contract specific and highly related to lack of scientific certainty in the current and expected amount of soil carbon sequestration in the pilot area. To further explore the cost-effectiveness of this pilot and other soil carbon sequestration schemes a review of the absolute uncertainty inherent in different soil testing regimes and models needs to be investigated (including identification of more efficient techniques for soil testing).

Third, anecdotal evidence suggests that the type of farmer engaged in the pilot are the ‘usual suspects’ or ‘early adopters’ those high performing farmers which had already undertaken most of the ‘easy wins’ in soil carbon sequestration, e.g. Stubble retention, low soil disturbance, etc. So they really only had the high value added options to undertake – this could also explain why actions based contracts had such low uptake – our framers had already undertaken those ‘standardised actions’

Fourth, the ‘value’ of information was tested when in the middle of our initial site visits the government released the ‘Clean Energy Future Plan’ which had two components that we believe influenced our farmers costing of carbon:(i) clearly stated a price of Carbon (tax) at $23 increasing by 2.5% until 2015 when it would go to a market system, (ii) CFI which stated that they would pay for soil carbon. We expect that some farmers may have anchored their price to the published carbon tax whilst others may have held back on engagement with the pilot to see what price the Commonwealth (CFI) would give them and what restrictions were associated with their contracts.

The rates of soil carbon sequestration used in the pilot ranged around the 0.2 to 0.3 t CO_2e per ha per annum which is relatively low compared to other national estimates, e.g ranging from 0.5 to 1 t per ha per year. Of course these rates are considered low compared to some international examples which range up to 3 t CO_2e per ha per annum. This shows the high variability of soil carbon sequestration rates within Australia and internationally, showing that at the national level there is greater heterogeneity within the environmental conditions and pre conditions for soil carbon sequestration. Which leads to the potential that there are potentially areas which have greater storage potential and may be more cost-efficient than the Lachlan Catchment.

Of course, this pilot did not cover all issues with respect to SOC being involved in a national carbon scheme, for example; varying soil and climatic conditions, additionally and permanence were excluded. This was necessary due to resourcing and timescale of the project, but it does add extra complexity to the national scheme which will have to ensure SOC is considered in multiple soil and climatic conditions and in conjunction with methane and nitrous oxide emissions on farm as well as making contracts for 100 years not 5 years as done in this project.

Concluding comments

In conclusion the paper has found that the design of a soil carbon sequestration scheme needs to be undertaken in a considered way to ensure cost-effectiveness. There is a need to particularly focus on contract choice and associated transaction costs (i.e. soil testing regimes) and the type of landholder that is engaged in the project. However, the viability of soil carbon sequestration relative to other carbon sequestration or mitigation measures is potentially questionable based on our transaction cost estimates. Further work needs to be undertaken to test cost-efficiency of soil carbon sequestration in varying environmental conditions with larger scale projects (i.e. involving more and diverse farmers) and using different soil testing regimes (i.e. transaction cost options).

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