The Australian Journal of
Agricultural and
Resource Economics

Journal of the Australian Agricultural and Resource Economics Society

The Australian Journal of Agricultural and Resource Economics, 57, pp. 234–252

Measurement of greenhouse gas emissions from agriculture: economic implications for policy and agricultural producers*

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If agriculture were to be included in Australia's carbon price scheme, a key decision for government would be how to estimate greenhouse gas emissions. We explore the consequences of three different methods for measuring on-farm emissions: national accounting methods, an amended version of those methods and use of best-available local data. Estimated emissions under the three methods can vary widely; for example, on a case study farm in Western Australia, local data indicated 44 per cent lower emissions than did the national accounts method. If on-farm emissions are subject to an emissions price, the impact on farm profit is large and varies considerably with different measurement methods. For instance, if a price of $23/t of CO2-e applies then farm profit falls by 14.4–30.8 per cent depending on the measurement method. Thus, the choice of measurement method can have large distributional consequences. On the other hand, inaccurate measurement results in relatively minor deadweight losses. On-farm sequestration through reafforestation may lessen the impact of an emissions price on farm businesses, although it will require a high carbon price to be viable, especially if sequestration rates are underestimated or low.

Key words: economic modelling, emissions measurement, greenhouse gas accounting methodology, nitrous oxide, sequestration.

1. Introduction

The Australian government, like many governments, is adopting policies and initiatives to reduce emissions of greenhouse gases (GHGs). An emissions trading scheme (ETS) comes into effect on 1 July 2012, initially with a fixed price of $AUD23 per tonne of carbon dioxide equivalent (CO_2-e). Further, over $1.7 billion is being invested in Australia's land sector from 2011 to 2016 to reduce and offset GHG emissions.

* The authors are grateful to the University of Western Australia, Grains Research and Development Corporation, the Australian Research Council and the Future Farm Industries CRC for their funding and support. Louise Barton and Bill Bowden must also be thanked for the counsel and unpublished data they provided which aided the development of the different GHG accounting methodologies.

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doi: 10.1111/j.1467-8489.2012.00613.x

Agriculture accounts for 16 per cent of Australia's GHG emissions, yet is excluded from the ETS, at least in its initial stages, and so Australian agriculture will mainly be affected indirectly by the establishment of a price on emissions. Other sectors covered by the ETS, such as electricity generators and processors, will pass on to farmers their higher costs and/or use farm land as a source of emission offsets via carbon sequestration.

Although initially excluded from the scheme, agricultural emissions nonetheless are measured or estimated and reported in the national inventory of emissions using methods outlined in the National Inventory (2011). There is the prospect that agriculture may be included in the scheme at a future date. Under either scenario–agriculture excluded or included in an ETS–accurate measurement of agricultural emissions is important.

The National Inventory methods predict emissions using parameters based upon peer-reviewed science. For countries like Australia, however, this can be problematic as most studies of agricultural emissions that are the sources of these standard parameters consider Northern Hemisphere agriculture (Galbally *et al*. 2005; Stehfest and Bouwman 2006; Barton *et al*. 2008), yet Australian soils, climate and agricultural operations can be very different. To mitigate this, standard parameters are sometimes updated with country-specific values. However, there are often substantial regional differences in rates of emissions, attributable to differences in climate, soils and agricultural practices (Berdanier and Conant 2012), especially in a large country like Australia. National accounting methods typically lack the detail and spatial resolution to accommodate all these differences (Williams *et al*. 2012).

It is therefore perhaps not surprising that one reason stated for excluding agricultural emissions from the ETS in its early years is that they are hard to quantify. Knowledge of their spatial and temporal variation is often poor (Leip *et al*. 2011; Misselbrook *et al*. 2011; Berdanier and Conant 2012), and this impedes formulation of efficient policies to lessen agricultural emissions (e.g. Rypdal and Winiwarter 2001).

Thus, the accuracy of methods for estimating agricultural emissions is important for policy. On the one hand, agriculture is a significant source of emissions (Garnaut 2008), yet knowledge about emissions on actual farms in different environments is often inadequate. Addressing these knowledge gaps would involve transaction costs, so one possible response by policymakers is to apply a uniform national formula-based approach to estimation of emissions. Alternatively, programs could use more accurate (but more expensive) approaches that account for variations over time, space and farming practices. In this article, we investigate three different measurement methods, including the national accounting method. We outline the farm business and emission consequences of applying these different emission measurement methods when carbon prices and different emission policy scenarios apply to agriculture.

Our analyses use the central grainbelt of Western Australia as a study region. This region is known to have agro-climatic conditions (semi-arid) that typically are not well represented by the emissions factors in the national inventory accounting system (Galbally *et al.* 2005; Barton *et al.* 2011). However, local scientific data on emissions (particularly of N_2O) exist for the study region (Figure 1) (e.g. Barton *et al.* 2008, 2010, 2011; Li *et al.* 2011).

The article is structured as follows. The next section includes outlines of the farm modelling approach, the methods for estimation of emissions, the representation of carbon pricing and the associated emissions policy scenarios investigated. We then present and discuss our results before drawing conclusions.

2. Methods

2.1. Farm modelling

MIDAS is a detailed steady-state optimisation farm model that accounts for biological, managerial, financial and technical aspects of dryland farming. Originally developed in the mid-1980s (Kingwell and Pannell (1987), later versions of MIDAS and/or examples of its applications relevant to GHGs are described by Kingwell *et al.* (1995), Petersen *et al.* (2003), Kopke *et al.* (2008), Kingwell (2009), Doole *et al.* (2009) and Kragt *et al.* (2012).

The Model's objective is to maximise farm profit after deduction of all operating costs, overhead costs, depreciation and opportunity costs associated with farm assets (exclusive of land) from production receipts. The several hundred activities in MIDAS include alternative rotations on each of eight

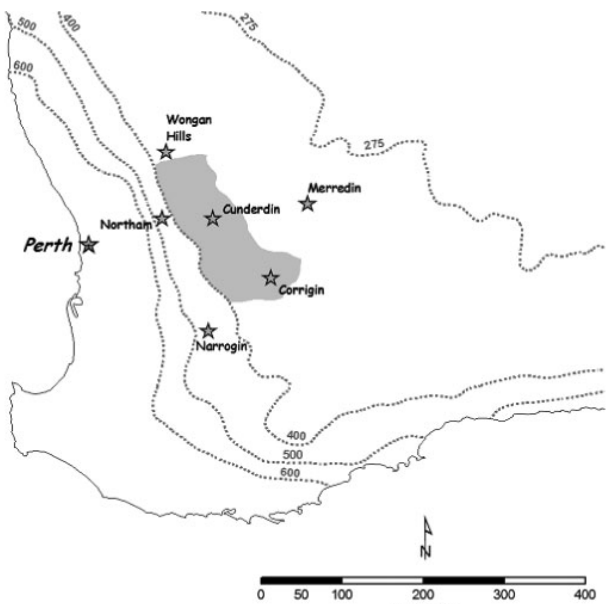

Figure 1 The central grainbelt represented by this MIDAS model with rainfall isohyets in mm. Source: Gibson *et al.* (2008).

soil classes (S1–S8), crop sowing opportunities, feed supply and feed utilisation by different livestock classes, yield penalties for delays to sowing, cash flow recording and machinery and overhead expenditures. The model's solution is the set of activities that draws on farm resources to generate maximum profit subject to a range of constraints. Constraint types include resource constraints (e.g. on several different qualities of land, on machinery capacity), technical constraints (e.g. representing the demand for, and supply of, animal feed), logical constraints (e.g. determining the number of 3-year-old sheep depending on the number of 2-year-old sheep the previous year and the number of sales and purchases of sheep of relevant ages) and financial accounting constraints.

Although versions of MIDAS exist for various regions (e.g. Flugge and Schilizzi 2005), the model used in this article represents a typical 2000 ha farm in the central grainbelt of Western Australia. The region is characterised by a Mediterranean climate with long, hot and dry summers and cool, moist winters (June–August) and a growing season (May–October) during which about 75 per cent of the 350–400 mm annual rainfall occurs. A typical farm engages in a mix of cropping and livestock enterprises across the soil types listed in Table 1. The crops grown include wheat, barley, oats, lupins, canola, field peas, chickpea and faba beans. These are sown in rotation with legume pastures including annual subterranean clover and serradella and perennial lucerne. Sheep, mostly Merino breeds, graze these pastures, producing wool and meat.

2.2. Inclusion of agricultural emissions and a carbon price in MIDAS

MIDAS was updated with cost and price structures that were the average of real prices from 2007 to 2011. It was also modified to include: a carbon price; options to sequester carbon in trees; and formulas for estimating GHG emissions from farm activities, based on those in national GHG accounts.

Table 1 The eight soil types in the MIDAS model

	Name	Main soil types	Area (ha)
S1	Poor sands	Deep pale sand	140
S2	Average sandplain	Deep yellow sand	210
S3	Good sandplain	Yellow loamy sand	350
S4	Shallow duplex soil	Sandy loam over clay	210
S5	Medium heavy	Rocky red/brown loamy sand/sandy loam; Brownish grey granitic loamy sand	200
S6	Heavy valley floors	Red/brown sandy loam over clay; Red/grey clay	200
S7	Sandy-surfaced valley	Deep/shallow sandy-surfaced valley floor	300
S8	Deep duplex soils	Loamy sand over clay at depth	390

2.2.1. Representing a carbon price in MIDAS

Input prices in MIDAS were adjusted upwards to account for the impacts of the ETS on input suppliers. Although initially all fuel use economy-wide will be excluded from a carbon price, the government intends to apply the carbon price to heavy transport vehicles from 2014 (Australian Government 2011). Hence, in the medium term, goods and services dependent on energy and transport will become more expensive. In this analysis, fuel used by heavy haulage vehicles was assumed to be subject to a carbon price.

To model cost increases attributable to a carbon price, this study adopted the approaches of Keogh and Thompson (2008) and Kingwell (2009) who related increases in the transport/haulage fuel price attributable to a carbon price to goods and services used by farm businesses. To illustrate, combustion of one litre of diesel produces 2.7 kg of CO_2-e (NGA Factors 2010). For each \$10 increment in the carbon price, the price of transport fuel would rise by 2.7 cent/L. Following Keogh and Thompson (2008) and Kingwell (2009), simple flow-on cost factors based mostly on fuel costs (see Table 2) applied to a range of farm inputs and services. As an example, if transport fuel prices increased by 5 per cent, then chemical costs would be expected to increase by 1.25 per cent (that is, 25 per cent of 5 per cent). However, some revisions to the cost-flow through factors of Keogh and Thompson (2008) and Kingwell (2009) occurred as their analyses were based on a previous policy proposal in which the carbon price would have applied to all fuel use, economy-wide.

Inputs like fertilisers and chemicals may not become much more expensive under the current carbon-pricing policy. Although their manufacture is energy-intensive, only domestic producers of these inputs will face higher costs. Australian manufacturers of farm inputs that compete with imported substitutes not subject to a carbon price will have a limited ability to pass on the domestic carbon price to their customers. Therefore, the impact of a carbon price on these farm inputs is likely to be minimal (Tulloh *et al.* 2009). Finally, because the major products from farms in the study region are unprocessed exports (e.g. wheat, wool, live sheep), we assumed that commodity sale prices would be unchanged by the establishment of a carbon price in Australia.

Table 2 Factors for the flow-on of a carbon price for various farm inputs (based on Kingwell 2009)

Farm input	Flow-on cost factor	Farm input	Flow-on cost factor
Contract seeding	0.15	Shire rates	0.10
Contract harvesting	0.15	Repairs and maintenance	0.15
Shearing	0.15	Grain handling	0.30
Sheep work	0.15	Transport	0.25
Fertiliser	0.25	Hired labour	0.15
Chemicals	0.25	Professional fees	0.05
Electricity	1.00	Fuel (transport)	1.00
Livestock processing	0.15	Fuel (on-farm)	0.05

2.2.2 Methods for estimating agricultural emissions

The following sources of on-farm emissions were accounted for in the model using units of CO_2-e: CH_4 from enteric fermentation; N_2O from animal waste, N fertiliser, biological N-fixation and crop residues; and CO_2 from urea hydrolysis. With a carbon price, the cost of fuel used on-farm was assumed to increase by 5 per cent (Table 2) due to extra handling costs before it reaches the farm. If agriculture was included in the carbon-pricing mechanism, then we assumed that emissions from fuel used on-farm for activities like crop establishment and harvest would count as agricultural emissions and so accordingly these emissions were included with those sources listed above.

The amount of on-farm emissions produced from these sources was estimated using three different GHG accounting methods:

1. Standard. The standard method used by the Australian Government in their national GHG accounting, as outlined in the National Inventory (2011).
2. Amended. The National Inventory (2011) uses a process-based approach to estimate emissions, but in our judgement the approaches used for some sources of emissions are inconsistent with actual processes. For example, determining N_2O emissions from N-fixation requires quantification of how much N has been fixed. The National Inventory (2011) quantifies N fixation based upon just the N content of legume stubble and fails to account for N removed in grain. Furthermore, the inventory accounts for N_2O emissions from N fixation and residues for legume crops, but for legume pastures, only N fixation is considered, ignoring that these pastures have N-rich residues. In the amended accounting method, these inconsistencies were corrected.
3. Local. Where local scientific data exists, the Amended method was adapted and modified based on the best available results of local field trials conducted in the study region.

Exact detail of the assumptions and formulas used for each method is contained in the Appendix S1.

MIDAS was modified by inserting transfer rows for each of these aforementioned sources of agricultural emissions into the matrix. For every activity (column) in MIDAS that may cause any of these emissions, a positive coefficient was inserted into the transfer row for that emission. This coefficient was set to the value (i.e. amount of emissions) estimated for that activity by the formulas in the Appendix S1. Consequently, this value often changed depending on which GHG accounting methodology was used. For instance, a hectare of pasture-pasture-wheat rotation on soil type S3 would produce 16, 105 or 9 kg of CO_2-e/year of N_2O emissions from the decomposition of crop residues when Standard, Amended or Local methods were used, respectively. When a carbon price was placed directly on agricultural emissions, the transfer rows were constrained to zero and the model forced to satisfy this constraint by undertaking sequestration or paying the carbon price–activities which both had negative coefficients in the matrix.

2.2.3. Sequestration

The option of being able to revegetate land to sequester carbon was also investigated. As with emissions, the amount of sequestration could be estimated using different methodologies. One option would be for governments to rely on the national GHG accounting methodologies such as the Australian Greenhouse Office's National Carbon Accounting Toolbox (NCAT) *FullCAM* model. NCAT was developed by combining process and empirical modelling at the continental scale (Jonson 2010) and, like the Standard method for estimating emissions, was not originally intended for use at the farm-level. Alternatively, sequestration could be estimated from locally collected data. To represent this option, we used a non-symmetrical sigmoidal growth pattern, developed from data on tree growth in the study region (Jonson 2010). Although NCAT's predictions of sequestration are much lower than locally measured data for the study region, both exhibit a broadly similar trend whereby the rate of carbon accumulation decreases over time, eventually plateauing after around 50 years. To ensure conservatism and to provide a 'buffer against the risk of reversal', estimates of sequestration were reduced by 5 per cent (DCCEE 2010).

Estimating the revenue from sequestration required translating, the future returns from carbon sequestration into a form compatible with MIDAS, which represents a single year of production, assumed to be in a cyclical steady state (costs in MIDAS were assumed to stay constant in real terms). To do this, a stream of sequestration payments in future years was estimated using the aforementioned NCAT or local data–depending on the scenario under investigation–and an assumed carbon price. This stream of payments was then discounted (using a rate of 7 per cent p.a.) and converted into an annuity to give the equivalent annual revenue expected from sequestration. The annuity was included in the MIDAS model as the annual sequestration income from planted trees. A similar technique was employed by Jonson (2010) and Kingwell (2009), except that in the current analysis, we assume that sequestration is claimed for 50 years (when tree growth 'plateaus'), and that the carbon in the trees then has to be maintained for a further 100 years past the cessation of sequestration, in accordance with permanency requirements of Australia's relevant policy, the 'Carbon Farming Initiative' (DCCEE 2010).

The carbon price used in each scenario represents an initial starting price which is assumed to increase at 2.5 per cent[1] p.a. in real terms for the first 3 years. For the purpose of this analysis, it is assumed that national and/or international politics result in a lack of political will to further increase the

[1] This rate of increase is used in Australia's recently legislated carbon tax, with a \$23/t of CO_2-e initial price.

price (in real terms) after 3 years. If we were to assume further price increases, then the differences in results between scenarios would be increased, increasing the importance of accurate measurement of emissions.

2.3. Policy scenarios

Three policy scenarios were considered:

1. 'Business-as-usual'. There is no price on emissions. Emissions have no impact on profit-maximising farm management decisions.
2. A carbon price is imposed domestically but on-farm emissions are excluded, as per current legislation. Under this scenario farmers can undertake (Kyoto-compliant) revegetation for sequestration.
3. A carbon price is imposed domestically, including on-farm emissions. As a 'trade-exposed' industry, agriculture is granted 'free permits' to partially shield it from adverse consequences of carbon pricing. If there are 'excess' free permits, scenarios are examined when their on-selling is either allowed or prohibited.

For the last two scenarios, we explore the consequences of using an inaccurate accounting method for farmers and then examine the implications for policy efficiency.

3. Results and discussion

3.1 Business-as-usual: greenhouse gas emissions and farm profit

All the results in this sub-section relate to the scenario where there is no price on emissions.

In this case, the optimal farming system has 73 per cent of the arable land allocated to crop and generates an annual profit of $96,800. This is consistent with survey results showing that farmers in the study region tend to crop about 70 per cent their arable land (Planfarm 2010). Around this optimal strategy, a region of high profit (within 12.5 per cent of the maximum) occurs where approximately 55–85 per cent of the farm is cropped (Figure 2). Reasons for the occurrence of relatively flat pay-off regions like this are outlined by Pannell (2006).

If on-farm emissions are estimated with the Standard method, then under steady-state optimal management, the 2000 ha farm emits 1062 t of CO_2-e/year. Of this, more than half (554 t of CO_2-e/year) is associated with livestock–mainly CH_4 from enteric fermentation, but also N_2O from animal waste. Other sources include 263 t of CO_2-e/year from N_2O as a result of N fixation, 124 t of CO_2-e/year from N_2O released during the decomposition of residues, 79 t of CO_2-e/year from fertiliser use (N_2O and CO_2 from urea hydrolysis) and 41 t of CO_2-e/year from fuel used on-farm.

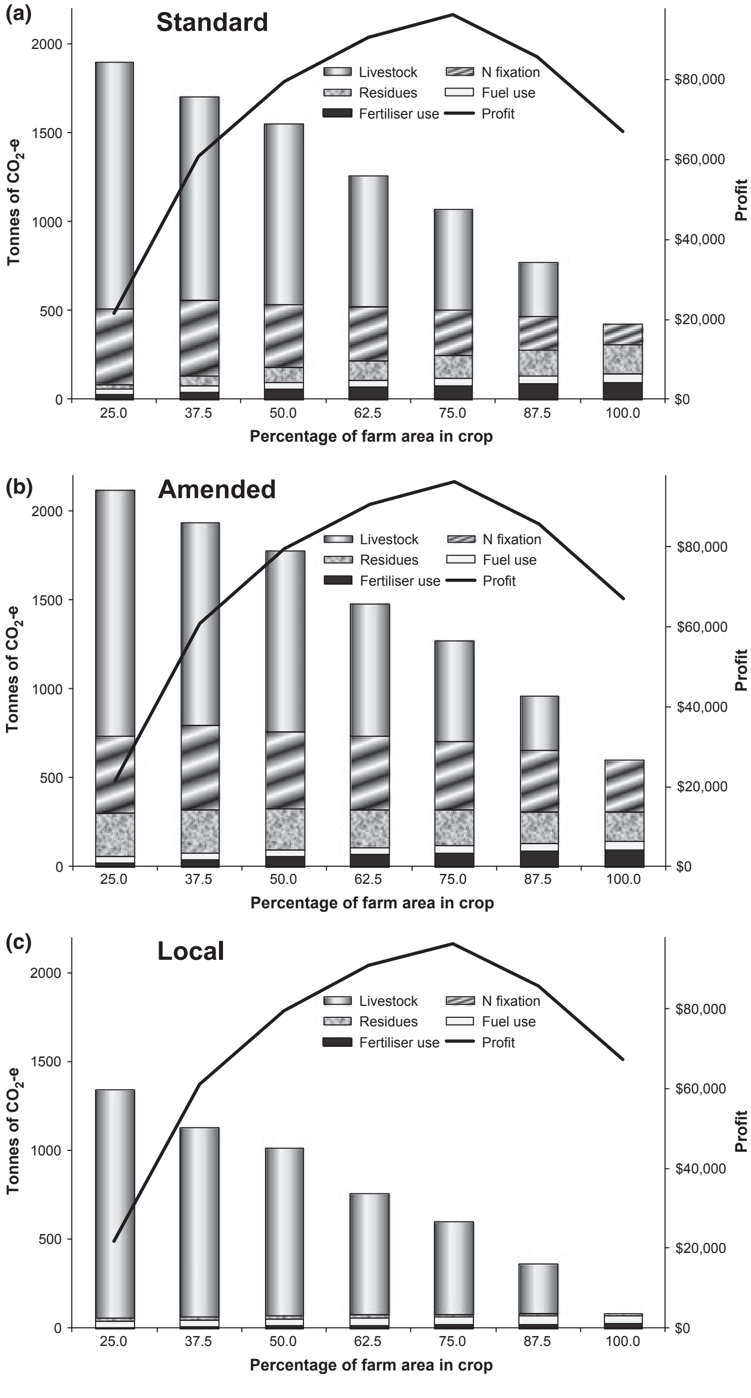

Figure 2 Profit and annual on-farm emissions as function of the proportion of the farm allocated to cropping in a 'business-as-usual' scenario, as estimated using (a) Standard (b) Amended or (c) Local methods.

If the farming system is constrained to operate at different levels of cropping intensity (Figure 2a), emissions from livestock decrease as the area of cropping increases. Because pasture swards typically contain appreciable proportions of legumes, and because the Standard method fails to account for the N fixed by crops that is removed in pulse grain (see Section 2.2.2.), estimated emissions from N fixation tend to increase when less area is used for cropping. Emissions from the decomposition of residues, fuel and fertiliser use increase with the area sown to crop, but they are relatively minor sources of GHGs. Hence, as the amount of land allocated to cropping increases the overall quantity of agricultural emissions falls considerably.

Using the Amended accounting method the on-farm emissions for the optimal farming system (given no carbon price) are 1267 t of CO_2-e/year (Figure 2b) (up from 1062 t for the Standard method). One of the Standard method's inconsistencies is its failure to account for the N-rich residues of legume pastures. Addressing this irregularity leads to emissions from residues increasing rather than decreasing as the amount of crop in the farming system is reduced. Yet at the same time, when the N fixed by pulse crops that is removed in the harvested seed is also taken into account in the Amended method, emissions from N fixation at higher proportions of crop are larger than estimates based on the Standard method. Hence overall, on-farm emissions estimated with the Amended method are higher compared with the Standard method, especially for livestock-dominant farms.

Alternatively, if the Local method is used, on-farm emissions are estimated at only 592 t of CO_2-e/year for the optimal farming system (Figure 2c). That is 56 per cent of that estimated with the Standard method. N_2O emissions from fertiliser, residues and N-fixation are much smaller when estimated with the Local method. Such differences between methods reflect the localised characteristics of N_2O emissions (e.g. Galbally *et al.* 2005), a finding consistent with N_2O from agricultural soils being the most uncertain source of emissions in national inventories (Rypdal and Winiwarter 2001). Recorded N_2O emissions in the study region are minimal compared with other semi-arid regions, perhaps because rainfall, soil organic matter levels, N inputs and the use of tillage that incorporates stubble all tend to be relatively low in this area (Li *et al.* 2011). This makes the dominance of livestock in the farm's emissions profile even greater.

In summary, compared with the Standard accounting method, the Amended method indicates that emissions are higher, due to capturing higher emissions related to N fixation and pasture residues, while under the Local method, emissions are substantially lower, mainly due to much lower emissions from cropping. The results for the Local method are specific to this region, but they highlight that reliance on standard national values will result in errors in some regions, potentially disadvantaging some farmers and advantaging others.

3.2. Carbon price imposed but agriculture excluded

The results in this sub-section relate to the policy scenario where there is a price on carbon, but agricultural producers are not required to pay for on-farm emissions. Because of this, the different emissions accounting methods outlined earlier do not influence farm management (or profit) in this scenario. Within this scenario, two possibilities are considered: claiming of offsets for carbon sequestration on farms may be disallowed or allowed. The later possibility represents the situation recently legislated in Australia. The sub-section is included to provide a base line in comparison with later results.

3.2.1. No sequestration can be claimed

Imposing a domestic carbon price that excludes on-farm emissions has little impact on the proportion of the farm allocated to cropping: the range of cropping percentages with high farm profits continues to be 55–85 per cent (Figure 3)[2]. Compared with the business-as-usual scenario, the profit of the optimal farming system falls by \$5700 (or 5.9 per cent) to \$91,100 at a carbon price of \$23/t of CO_2-e or by \$12,400 (12.8 per cent) to \$84,400 at \$50/t of CO_2-e. Farm profitability falls as price-taking, export-orientated farms in the study region cannot pass on the higher input costs caused by the impost of the domestic carbon price on other sectors of the economy. The higher costs are not because of charges for agricultural emissions, which are excluded in this policy scenario.

3.2.2 With voluntary claiming of on-farm sequestration

Allowing farmers to sell offsets for carbon sequestered by the voluntary revegetation of their land may reduce the impact of a carbon price on farm businesses (Flugge and Schilizzi 2005). A high carbon price favours sequestration as it both reduces the viability of other land uses that the revegetation would displace and also increases the price for which the stored carbon could be sold. If sequestration rates were estimated based on tree growth measured locally in the study region (Jonson 2010), then an initial price of at least \$34/t of CO_2-e is required before it is optimal to revegetate some of the farm's soil types that have a low opportunity cost (results not shown). With an initial price of \$50/t of CO_2-e, farm profitability would fall by \$4,500 (4.6 per cent) to \$92,300 (as opposed to 12.8 per cent in the absence of sequestration) (Figure 3). In this scenario, the impact of higher carbon prices on farm profit is less than predicted by other studies (e.g. Keogh and Thompson 2008). As well as allowing for sequestration, other likely reasons for this difference include that this study allows for changes in farm management in response to the

[2] This differs from Kingwell (2009) who found that the viability of livestock would increase slightly relative to cropping which tended to be more input-intensive. We attribute this to the carbon price not applying to fuel used on-farm in the current study (in accordance with more recent legislation), and also the factoring in of increases in the cost of processing livestock domestically.

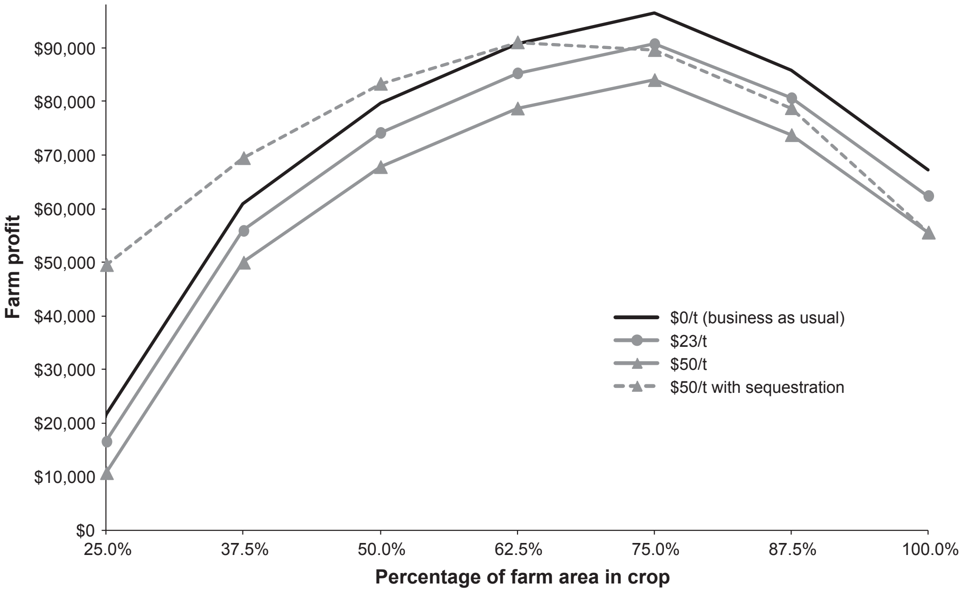

Figure 3 Farm profitability when agricultural emissions are not covered by an initial carbon price of either \$23 or \$50/t of CO_2-e with or without sequestration estimated using local data from (Jonson 2010).

carbon price and for the existence of different quality soil types with differing profitability for each enterprise.

If instead of using local data, carbon sequestration is estimated using the NCAT model, income from sequestration is reduced sixfold. This means an initial price in excess of \$220/t of CO_2-e is now required before sequestration appears in the optimal solution (results not shown).

In summary, the impact of a carbon price that does not include agriculture depends on the carbon price and on whether farmers receive payments for sequestration offsets. Payments for sequestration can offset some or all of the losses due to higher costs resulting from the carbon price, but only at high carbon prices.

3.3. Carbon price imposed with agriculture included

This sub-section relates to the policy scenario where there is a price on carbon, and agricultural producers are required to pay directly for their emissions, as well as being affected by higher input costs. Under this scenario, farmers can respond to the price for on-farm emissions through a combination of altering farm operations to reduce emissions, using sequestration to abate emissions or paying the carbon price.

3.3.1. No free permits

With the inclusion of on-farm emissions, a carbon price has a substantial impact on farm profits. For instance, applying the Standard emissions accounting method and using an initial price of \$23/t of CO_2-e, the profit of the optimal farming system falls to \$67,600 (Table 3), a \$23,500 (25.7 per cent) reduction compared with the scenario where agricultural emissions are excluded from the carbon price (Section 3.2). In Section 3.1, estimated emissions were the greatest with the Amended method, and thus a carbon price on agricultural emissions has the greatest impact with that method (Table 3). With the Local method, estimates of on-farm emissions are smaller and so profit of the optimal farming system at \$23/t of CO_2-e is \$78,000, a reduction of \$13,100 (14.4 per cent) compared with when agriculture is excluded. Clearly in this case, the method used for emissions measurement at the farm-level has a substantial impact on farm profit.

For mixed farming systems, the impact of a carbon price on agricultural emissions would be worse in situations conducive to livestock production (Flugge and Schilizzi 2005), such as when livestock prices are high relative to grain prices. This is due to the large emissions of CH_4 attributable to livestock (Figure 2). It therefore follows that as the carbon price increases, the optimal farming system shifts further towards cropping to reduce on-farm emissions.

Estimates of sequestration are much smaller when NCAT is used compared with locally accurate data, meaning a much higher carbon price is required for afforestation to become viable (Section 3.2.2). Hence, at \$50/t of CO_2-e, no land would be revegetated with NCAT but 325 ha would be afforested if sequestration occurred at the rate reported by Jonson (2010). Hence, again the measurement method used is very important in influencing land use, farm profitability and the levels of emissions and sequestration.

In summary, farmers' profits depend on the method used to measure emissions and sequestration and, without free permits, are highly sensitive to the inclusion of agriculture in the carbon price.

Table 3 Characteristics of the optimum farming system when agricultural emissions estimated with different methods are included in the carbon price. Percentages in parentheses show the change relative to agriculture's exclusion

Emissions method	On-farm emissions (t of CO_2-e/year) (%)	Crop area (ha)	Sheep (DSE)	Revegetated area (ha)	Farm profit (\$'000) (%)
Initial carbon price of \$23/t of CO2-e (Sequestration unviable)					
Standard	955 (−8.5)	1503	2662	0	67.6 (−25.7)
Amended	1153 (−7.7)	1504	2656	0	63.1 (−30.8)
Local	564 (−2.1)	1472	2934	0	78 (−14.4)
Initial carbon price of \$50/t of CO2-e (Sequestration estimated with National Carbon Accounting Toolbox)					
Standard	516 (−50.5)	1820	507	0	40.2 (−52.4)
Amended	694 (−44.4)	1820	507	0	31.2 (−63.1)
Local	280 (−51.4)	1720	1199	0	59 (−30.1)
Initial carbon price of \$50/t of CO2-e (Sequestration rate from Jonson (2010))					
Standard	407 (−59.3)	1585	253	325	55.1 (−40.3)
Amended	531 (−55.3)	1600	139	325	47.6 (−48.4)
Local	255 (−54.3)	1462	1114	325	70.4 (−23.7)

3.3.2. Agriculture is given free exemptions/permits

Under the current carbon-pricing mechanism legislation, some 'trade-exposed' industries whose emissions are included in the ETS receive 94.5 or 66 per cent shielding (Australian Government 2011). We therefore analyse a situation where farm businesses are granted free exemptions/permits for 66 or 94.5 per cent of what their emissions would be at that carbon price if agriculture was excluded.

The on-farm emissions shown in the second column of Table 3 represent the point where the marginal opportunity cost of changing production to reduce emissions equals the marginal benefits of reducing payments for emissions. The granting of free exemptions/permits has no impact on the make-up of the optimal farming system (and hence also the level of on-farm emissions) if the quantity granted is less than these on-farm emissions, but it does counter reductions in farm profit (see the results for 66 per cent free permits are shown in Table 4). However, if the quantity granted is greater than the optimal level of on-farm emissions at that carbon price (i.e. there is an 'excess' – see results for Standard and Amended with 94.5 per cent free permits in Table 4) then the effect of free permits depends on the policy settings. One possibility is that farms can sell any excess permits to emitters in other industries. Comparing Table 3 with Tables 4 and 5 reveals that this would not alter the optimal farming strategy, but would provide a windfall to farmers.

Alternatively, if policy rules prohibit the sale of permits and more permits are issued than the farm would emit at that carbon price in the absence of free permits/exemptions, then it becomes optimal to increase on-farm emissions to the exact level of free permits (Table 6). Thus, with on-selling prohibited the granting of free permits also reduces the impact of including agriculture in the ETS. Prohibiting or allowing on-selling of excess permits would not change government revenue because the same amount of permits/exemptions is issued (so the net reductions in emissions would also be equal). However, the cost to society of these emissions reductions would be greater if the

Table 4 Characteristics of the optimal farming systems with an initial price of \$23/t of CO_2-e (where sequestration is unviable) and the granting of free permits/exemptions which could be on-sold

Emissions method	Free permits (t of CO_2-e/year) (%)†	On-farm emissions (t of CO_2-e/year) (%)†	Crop area (ha)	Sheep (DSE)	Excess free permits sold (t of CO_2-e/year)	Farm profit (\$'000) (%)†
Standard	689 (66)	955 (−8.5)	1503	2662	0	83.5 (−8.3)
Amended	825 (66)	1153 (−7.7)	1504	2656	0	82.0 (−10)
Local	380 (66)	564 (−2.1)	1472	2934	0	86.8 (−4.8)
Standard	986 (94.5)	955 (−8.5)	1503	2662	31	90.3 (−0.8)
Amended	1181 (94.5)	1153 (−7.7)	1504	2656	28	90.2 (−1)
Local	544 (94.5)	564 (−2.1)	1472	2934	0	90.5 (−0.6)

†Numbers in parentheses show per cent of emissions or profit when agriculture is excluded from the carbon price.

Table 5 Characteristics of the optimal farming systems with sequestration estimated using either National Carbon Accounting Toolbox (NCAT) or Jonson (2010) at the initial price of \$50/t of CO_2-e and the granting of free permits/exemptions which can be on-sold

Emissions method	Free permits (t of CO_2-e/year) (%)†	On-farm emissions (t of CO_2-e/year) (%)†	Revegetated area (ha)	Excess free permits sold (t of CO_2-e/year)	Farm profit (\$'000) (%)†
Initial carbon price of \$50/t of CO2-e (Sequestration estimated with NCAT)					
Standard	689 (66)	516 (−50.5)	0	173	74.6 (−11.7)
Amended	824 (66)	694 (−44.4)	0	130	72.4 (−14.3)
Local	380 (66)	280 (−51.4)	0	100	78 (−7.6)
Standard	986 (94.5)	516 (−50.5)	0	470	89.4 (5.9)
Amended	1180 (94.5)	694 (−44.4)	0	486	90.1 (6.7)
Local	544 (94.5)	280 (−51.4)	0	264	86.2 (2)
Initial carbon price of \$50/t of CO2-e (Sequestration rate from Jonson (2010))					
Standard	660 (66)	407 (−59.3)	325	253	88 (−4.6)
Amended	784 (66)	531 (−55.3)	325	253	86.7 (−6.1)
Local	368 (66)	255 (−54.3)	325	113	88.8 (−3.8)
Standard	946 (94.5)	407 (−59.3)	325	538	102.3 (10.8)
Amended	1123 (94.5)	531 (−55.3)	325	592	103.6 (12.2)
Local	527 (94.5)	255 (−54.3)	325	272	96.7 (4.8)

†Numbers in parentheses show per cent of emissions or profit when agriculture is excluded from a carbon price.

on-selling was prohibited because there would be less incentive for farmers to utilise any opportunities they have to reduce emissions for a lower cost per tonne than the emissions price.

There is an interaction between the effect of the different emissions accounting methods on profit and the granting of free permits. When no free permits are issued, there are big differences in emission liabilities and thus, especially at high carbon prices, large differences in farm profit arise between the emissions accounting methods (Table 3). Likewise, if on-selling occurs, then profit differences between the methodologies increase as the amount of excess free permits that are on-sold increases, especially at higher C-prices (Tables 4 and 5). However, when the level of free permits is similar to the level of on-farm emissions, or if the on-selling permits/exemptions is prohibited (Table 6), the profit difference between the methods narrows.

In summary, free permits greatly reduce the financial impact of carbon pricing on agriculture, without altering the level of emissions (unless excess permits are granted to farmers and they cannot be on-sold).

3.3.3. Implications of inaccuracy in methods

A major use of GHG accounting is to determine a country's emissions trend. Winiwarter and Rypdal (2001) suggest that uncertainty associated with methods used in GHG accounting may have minimal impact on trend estimates if sources of error behave similarly on a yearly basis. However, when polices like a carbon price are implemented to change these trends, measurement uncertainty could become problematic. It may result in the erroneous ranking

Table 6 Characteristics of the optimal farming systems when agriculture is included in the carbon price but shielded by the granting of free permits/exemptions which cannot be on-sold

Emissions method	Free permits (t of CO_2-e/year) (%)†	On-farm emissions (t of CO_2-e/year) (%)†	Revegetated area (ha)	Farm profit ($'000) (%)†
Initial carbon price of $23/t of CO_2-e (Sequestration unviable)				
Standard	689 (66)	955 (−8.5)	0	83.5 (−8.3)
Amended	825 (66)	1153 (−7.7)	0	82 (−10)
Local	380 (66)	564 (−2.1)	0	86.8 (−4.8)
Standard	986 (94.5)	986 (−5.5)	0	90.2 (−1)
Amended	1181 (94.5)	1181 (−5.5)	0	90.1 (−1.1)
Local	544 (94.5)	564 (−2.1)	0	90.5 (−0.6)
Initial carbon price of $50/t of CO2-e (Sequestration estimated with National Carbon Accounting Toolbox)				
Standard	689 (66)	689 (−34)	0	74.1 (−12.2)
Amended	824 (66)	824 (−34)	0	72.1 (−14.6)
Local	380 (66)	380 (−34)	0	77.7 (−8)
Standard	986 (94.5)	986 (−5.5)	0	83.6 (−1)
Amended	1180 (94.5)	1180 (−5.5)	0	83.5 (−1.1)
Local	544 (94.5)	544 (−5.5)	0	83.8 (−0.7)
Initial carbon price of $50/t of CO2-e (Sequestration rate from Jonson (2010))				
Standard	689 (66)	689 (−31.2)	325	86.8 (−5.9)
Amended	784 (66)	784 (−34)	325	84.7 (−8.3)
Local	368 (66)	368 (−34)	325	88.1 (−4.6)
Standard	986 (94.5)	986 (−1.5)	202	92.3 (−0.1)
Amended	1123 (94.5)	1123 (−5.5)	238	92.1 (−0.2)
Local	527 (94.5)	527 (−5.5)	192	92.2 (−0.2)

†Numbers in parentheses show per cent of emissions or profit when agriculture is excluded from the carbon price.

of the importance of different sources of emissions and the per-unit cost of reducing them. Our results show that an emissions policy based on incorrect estimates of emissions can result in emitters being charged for emissions that in reality are much different. Moreover, firm behaviour can be altered in ways that make the policy inefficient.

This efficiency loss is illustrated by comparing the Standard and Local accounting methods at a price of $23/t of CO_2-e with no sequestration allowed (Table 7). Compared with farm income and government revenue, deadweight losses of under $500 suggest that the inefficiency losses from using incorrect methods are relatively minor to society as a whole. However, the losses borne by particular groups (farmers or the government) will be much larger. In this case study, the Standard accounting method would significantly disadvantage farmers relative to a method based on more locally accurate data. There may be other parts of Australia where farmers are advantaged by the use of the Standard method.

As part of its package of legislation for the ETS, the Australian government also created the 'Carbon Farming Initiative'. This initiative allows farmers the option of claiming and selling offsets for voluntarily undertaking actions that mitigate emissions. The quantity of offsets that can be claimed for a given action is governed by a series of rules including one for 'leakage'.

Table 7 The implications of applying a \$23/t of CO_2-e price to the 2000 ha farm using accurate methods versus inaccurate methods

	Local method is accurate		Standard method is accurate	
	Local method is applied	Standard method is applied	Standard method is applied	Local method is applied
Cost to producer	−\$13,086	−\$23,451	−\$23,451	−\$13,086
Transfers to government	\$12,965	\$21,974	\$21,974	\$12,965
Benefits of abatement	\$278	\$1214	\$2036	\$320
Net benefit to society	\$157	−\$263	\$558	\$199
Deadweight loss	—	\$421	—	\$359

Leakage is when an action that mitigates emissions indirectly causes other emissions (potentially in another location, time or different form of GHG) to increase. As leakage nullifies abatement that would otherwise result from the mitigation activity, it must be subtracted when calculating net abatement. If this leakage is in the form of on-farm emissions and is incorrectly estimated at the farm level with methodologies used in national accounting, then it will either cause offsets to be more expensive than they should be or result in a net increase in atmospheric GHGs whilst giving the false impression that no net change in emissions had occurred due to the offset.

4. Conclusion

Different methods for measuring agricultural emissions can generate very different estimates of emissions. This article has explored, for different emission policy scenarios, the economic consequences of using different emission measurement methods, focusing on consequences for farmers. If agricultural emissions are covered under a carbon-pricing scheme, the emissions accounting method can significantly affect farm profit. The method for measuring carbon sequestration can also make a large difference to how much farm area is reafforested and thus also affects the impact of a carbon price on farm businesses.

Even if agricultural emissions are excluded from a domestic carbon price, the profit of a farm producing primarily for export markets will fall due to increased input costs. However, the reduction in profit is limited by competition from imported inputs not subject to the carbon price and/or government protection for local manufacturers and so substantial changes to the enterprise mix of the farming system is unlikely.

Sequestration may lessen the impact of a carbon price on farm businesses. However, for the farming system examined, a high carbon price is required for sequestration to be viable, especially if sequestration rates are low, or underestimated through use of an inaccurate measurement method.

If on-farm emissions are subject to a domestic carbon price, then the impact on farm profit (without compensation) is large, and agricultural emissions do reduce. Grazing production is most affected as livestock are the dominant source of emissions. Mixed cropping-livestock farming systems would become more crop orientated.

If a carbon price is applied to agricultural emissions that are incorrectly estimated, then the deadweight inefficiencies generated by inaccurate methods may not be large. It would, however, raise issues of equity and fairness as the impacts of inaccurate accounting methods on costs to producers and transfers to government can be large. Hence, the recent allocation of research funds under the *Filling the Research Gap* program (DAFF 2012) that aims to provide greater accuracy in emissions measurement is likely to be an appropriate investment.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Measurement of greenhouse gas emissions from agriculture: economic implications for policy and agricultural producers.

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