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Evaluating a tax-based subsidy approach for forest carbon sequestration

THEMATIC SECTION
Forest Ecosystem Services

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SUMMARY

Forest carbon sequestration plays an important role in reducing the build-up of greenhouse gases that are known to contribute to global climate change. However, private landowners will supply less carbon sequestration than would be socially desirable if they are unable to capture the economic value of sequestration. We examine the viability of offering landowners property tax subsidies for forest carbon sequestration (referred to as a 'tax-based subsidy approach'). Waiving property taxes on forestland provides incentives for landowners to afforest non-forested land and/or sustain forests that are at risk of deforestation. We focus on 17 Tennessee counties and one Kentucky county, constituting one of 179 Bureau of Economic Analysis areas in the United States, as a case study. Higher forestland net return from waiving property taxes increases the share of forestland in the 18 counties, which in turn increases the accumulation of carbon in the forest ecosystem, suggesting that this is a viable approach. The annualized county-level cost of supplying forest carbon sequestration using a tax-based subsidy ranges between US$15.56 and US$563.58 per carbon tonne across the 18 counties. Relevant government agencies can use these estimates to target selected counties for more cost-effective adoption of the county-level tax-based subsidy approach.

Keywords: forest carbon sequestration, incentive payment, tax-based subsidy

INTRODUCTION

There is a broad consensus that carbon emissions resulting from human activities contribute to climate change (IPCC 2014). In response, global efforts have been undertaken to reduce atmospheric carbon. Much attention has been focused on forest carbon sequestration in order to offset carbon emissions by preventing deforestation and encouraging afforestation. Forest carbon sequestration receives this attention for two reasons. First, the potential of forestland to offset carbon emissions is substantial. Forestland's potential in the USA was estimated at 905 million tonnes of carbon in 2011, an offset capacity of 16.1% of total US carbon emissions (or 13.5% of total greenhouse gas emissions) (USEPA 2013). Second, forest carbon sequestration has cost advantages compared to other carbon emission mitigation efforts (Mason & Plantinga 2011).

Despite the potential for forest carbon sequestration, reforestation and/or avoiding deforestation are complex issues that contend with deforestation pressures from agriculture and urban development. The primary complication is that the value of the sequestered carbon in forestland is not considered when making deforestation decisions for development. Economists commonly refer to the value of carbon sequestration as a positive externality and the phenomenon of not considering that value in decision making as a market failure. In efforts to internalize the positive externality into the deforestation decision-making process, incentive payment approaches for forest carbon sequestration have been explored (e.g., Lubowski *et al.* 2006; Mason & Plantinga 2011).

Incentive payment approaches for forest carbon sequestration have begun to be adopted in different regions of the USA. A prominent example is the cap-and-trade programme in California that includes providing payments to forest landowners for the carbon sequestration generated by their forests (CARB 2012). Other US States such as West Virginia, Tennessee, Maryland, North Carolina, Pennsylvania, Massachusetts, and Oregon have also implemented incentive payment systems in recent years (USEPA 2012). The rest of the world has also been keen on developing programmes that can help reduce emissions from deforestation and forest degradation (REDD) in order to lower greenhouse gas emissions. For example, the European Commission proposed a Global Forest Carbon Mechanism under the United Nations Climate Change Conference in order to finance developing countries' emissions reductions

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achieved by taking action to support REDD (EC 2016). Brazil also announced a national plan to reduce its deforestation rate by 80% by 2020 (compared with its average rate over the 1996–2005 decade) (Government of Brazil 2009).

Challenges exist for organizers and participants in implementing an incentive payment programme for forest carbon sequestration. Incentive payment planners wrestle with the institutional burden of creating a new programme and the financial burden of its implementation (Baldwin & Richards 2010). The barriers for landowner participation include concerns about low carbon prices, early withdrawal penalties, meeting additionality requirements and contract length (Markowski-Lindsay *et al.* 2011). Given these challenges, programmes that offer a property tax subsidy to forest landowners may be viable alternatives to incentive payment programmes for forest carbon sequestration. The administrative resources and systems needed to administer property tax subsidies (referred to as 'tax-based subsidies') to landowners are already in place (Dinan 2012). Thus, a tax-based subsidy may alleviate the institutional and financial burdens of designing payments and may ease some of the barriers to landowner participation.

Despite the potential of a tax-based subsidy approach to encourage forest carbon sequestration, many studies have focused primarily on the efficiency of different incentive payment approaches (Lubowski *et al.* 2006; Mason & Plantinga 2011). Although evidence supporting the merits of forest carbon sequestration is found in the literature, few if any studies explicitly consider a tax-based subsidy approach. The lack of such research is surprising given that income tax incentives are commonly used to protect land through different acquisition strategies (e.g. conservation easements). Our research attempts to fill the gaps in knowledge by examining the role of a tax-based subsidy approach for forest carbon sequestration.

We focus on a case study area of 17 Tennessee counties and one Kentucky county (Fig. 1), one of 179 Bureau of Economic Analysis areas in the USA (Johnson & Kort 2004). This area is selected as a case study due to its local and national importance to US carbon sequestration as part of the Appalachian region, which accounts for 20% of US forestland (Smith *et al.* 2009). Using the case study, we address three specific questions: (1) To what extent does the tax-based subsidy approach help to increase the accumulation of carbon in the forest ecosystem? (2) How cost effective could a tax-based subsidy approach be? (3) Is there spatial heterogeneity of carbon accumulation in forestland from implementing the tax-based subsidy approach?

METHODS

Two modelling efforts are required in order to address these questions. A land use model is constructed that compares the net returns from four broad land use categories: cropland, pastureland, urban land and forestland. (Five land use categories were defined, but the model required calculation of only four net returns; see S1 in the supplementary materials (available online).) The DayCent uses output from the land use model to simulate carbon sequestration as deciduous and evergreen trees grow (see the 'Carbon simulation model' section for a description regarding DayCent). As tax relief increases the net present value of forestland relative to other land uses, the amount of carbon sequestered increases and is measured using information from both models. These modelling efforts and others are described below.

Land use model

The land use model was estimated using multinomial logit regression. This method is used to predict the probabilities of three or more possible outcomes occurring for a categorically distributed dependent variable, given a set of explanatory variables (Greene 2012: 803–806). The multinomial logit model has an empirical advantage because the expected share of each land use category can be estimated as a linear combination of exogenous explanatory variables (Plantinga *et al.* 1999; Ahn 2008). (See S2 in the supplementary materials.)

Assuming a landowner maximizes utility, the probability of choosing a particular land use is related to the expected returns from all potential land uses since the landowner's utility is largely generated by the land use that provides the maximum expected return. We used time-lagged expected annual returns from each land use to represent their returns (i.e. returns in 2001 and 2006 for land use choices made in 2006 and 2011, respectively, based on the limited temporal replication in our land use data) (NLCD 2011). (See S1 in the supplementary materials for how expected annual returns were estimated for the four land uses.)

Potential multicollinearity among the expected annual returns from the four land uses was diagnosed and tolerances were such that the regression design could proceed. Because the study area is hilly and mountainous, the slope (i.e. average slope of 11°) may influence the land's suitability for some land uses (e.g. crop use and urban development) (Yang *et al.* 2008; Jin *et al.* 2015) and the high elevation (i.e. average elevation of 392 m) may influence land use choices through views related to development and the crops considered. Under such geophysical conditions, deforestation and land use changes may have been affected by slope and elevation (e.g. Nelson & Geoghegan 2002), and thus we controlled for these variables in the regressions.

Average elevation and average slope were measured using raster grids derived from the 30 m × 30 m digital elevation model (DEM) (USGS 2013). The average elevation and average slope for 1-km^2 pixels were calculated from the DEM data using the Zonal Statistics tool in ArcGIS 10.1 (ESRI 2012). We also included a year dummy variable indicating whether the land use choice was made in 2006 or 2011. This variable controls for differences in land use choices made over time due to changes in market conditions or other trend influences.

Because the coefficients obtained from the multinomial logit model are difficult to interpret directly, marginal effects

Table 1 Variable names, descriptions and statistics.

Variable	*Description*	*Mean (SD)*
Returns from forestland	Expected annual net returns from forest use at the county level (US$ per hectare)	50.15 (12.15)
Returns from pastureland	Expected annual net returns from pasture use at the county level (US$ per hectare)	49.54 (3.13)
Returns from cropland	Expected annual net returns from crop use at the county level (US$ per hectare)	54.31 (383.52)
Returns from urban land	Expected annual net returns for urban use at the census-block group level (US$ per hectare)	1059.35 (1541.02)
Slope	Average slope at pixel level (degrees)	10.60 (4.62)
Elevation	Average elevation at pixel level (metres)	392.08 (107.43)
Year dummy	1 if the land use decision was in 2011, 0 if the land use decision was in 2006	0.50 (0.50)

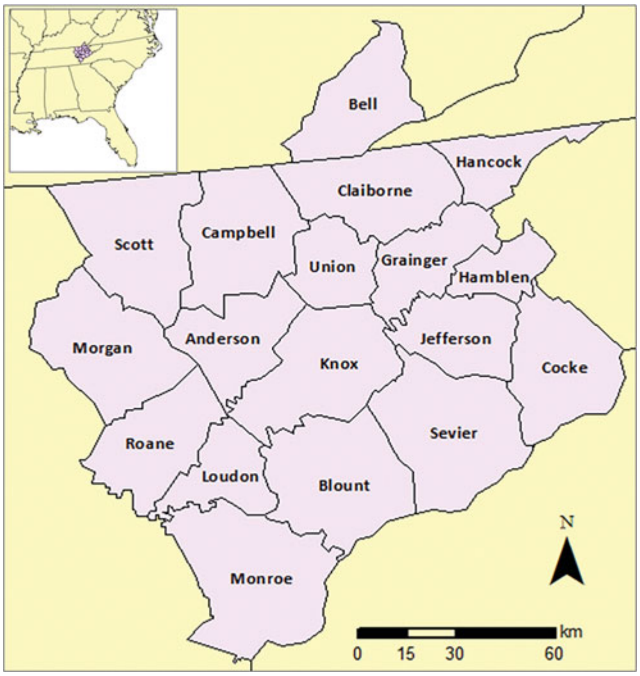


Figure 1 A map of the study area of the 17 Tennessee counties and one Kentucky county, one of 179 Bureau of Economic Analysis economic areas in the USA.

are calculated. (See S3 in the supplementary materials.) The marginal effects are used to predict changes in probabilities of forestland deforestation or afforestation of non-forested, non-developed land due to changes in forestland return. Those relationships are used to predict hectares of land afforested and/or preserved in forest due to tax-induced changes in forestland returns by comparing predicted land areas for a baseline scenario (i.e. observed land use returns in 2006) and a hypothetical scenario (i.e. forestland returns in 2006 less property taxes – zero property tax on forestland, assuming observed land use returns in 2006 for other land uses). Then, we employ a carbon simulation model to estimate how carbon sequestration is affected by the afforestation of non-forested, non-developed land or by the deterrence of deforestation due to tax-induced changes in forestland returns at the county level. (See Table 1 for the descriptive statistics regarding the returns of the four land uses.)

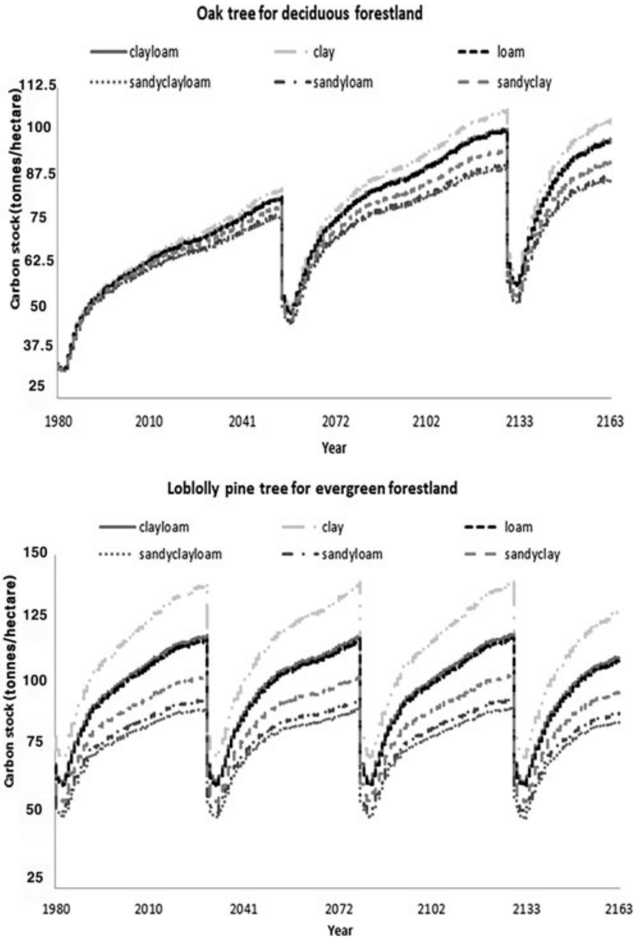
Carbon simulation model

A daily version of the Century model (referred to as the ‘DayCent model’) is used to trace gas fluxes (e.g. CO_2, N_2O, NO_x, N_2 and CH_4) for forestland (NREL 2016). The DayCent model has been used extensively to simulate the effects of changes in environmental factors and management practices on natural and managed plant-soil ecosystems at site, regional and global levels (Parton *et al.* 2001). The DayCent model includes sub-models of plant production, decomposition of dead plant material and soil organic matter, soil water and temperature dynamics, as well as tracing daily greenhouse gas fluxes (Parton *et al.* 2001). The plant production sub-model is used to simulate the growth of deciduous and evergreen forestland (hereafter called the ‘forest sub-model’). Oak and loblolly pine are dominant tree species in the study area, and thus the growth of oak trees and loblolly pine trees is simulated in order to represent the growth of deciduous and evergreen forestland, respectively (Southeast Exotic Pest Plant Council 2013). We assumed that the mixed forestland within a county is in the same ratio as the deciduous to evergreen forestland in the county, because the data source does not report the composition of mixed forestland. (See S4 in the supplementary materials.)

The 30 m × 30 m areas were aggregated for each of the five land use categories (i.e. crop, pasture, urban, forest and other) in order to calculate their shares within each 1-km^2 pixel. The distribution of deciduous, evergreen and mixed forest within each pixel was used in the DayCent model to estimate carbon densities in order to accommodate differences in potential carbon sequestration potentials. Non-taxable forestland in protected areas (i.e. all federal and most state conservation lands and many privately protected areas at regional and local scales) was excluded from the forestland use category by using the boundaries of current protected areas obtained from the Protected Areas Database of the United States (USGS 2013).

Carbon accumulation for each forestland type was simulated for 1980–2163 using the forest sub-model and information about climate, disturbance and management, as well as other environmental characteristics. The 1980–2163 period is long enough to accommodate complex factors that influence changes in the amount of carbon stored in a forest stand (e.g. harvest age, spread of root diseases, extent and severity of future fires, tree mortality caused by forest insects, rate of tree regeneration after disturbances, forest management practices and potential changes in forest productivity) (USDA 2014).

Carbon sequestration was calculated based on integrating monthly fluxes in order to account for the net balance of carbon uptake through photosynthesis against carbon losses. (See S5 in the supplementary materials.) A series of 12 DayCent models (i.e. 2 tree types × 6 soil types) was constructed and daily total carbon densities in tonnes per hectare were obtained for 1980–2163 by summing the carbon densities from carbon pools in forestland (i.e. live trees, standing dead trees, understory vegetation, down deadwood, forest floor and soil organic matter) (Fig. 2). Daily weather data for East Tennessee were acquired from the Oak Ridge National Laboratory Daymet data server from 1980 to 2163 (Thornton *et al.* 2014). The soil property data used in the DayCent model were from the Soil Survey Geographic Database (SSURGO) (USDA-NRCS 2012). Plant rotation schedules and management practices were obtained from University of Tennessee Institute of Agriculture Field Crop Budgets (UTIA 2014) and from the CENTURY User Manual (Peng *et al.* 1998).


Oak tree for deciduous forestland

Loblolly pine tree for evergreen forestland

Figure 2 Daily total carbon densities in tonnes per hectare for 1980–2163 (oak trees for deciduous forestland and loblolly pine trees for evergreen forestland).

Forecasting annualized cost of supplying forest carbon sequestration

Carbon densities were estimated under the baseline scenario and the hypothetical scenario. The former scenario used the land use model to predict land allocations in 2011 based on observed land use returns in 2006. The latter scenario used that model to predict land allocations for 2011 based on forestland returns in 2006 less property taxes, all other factors being constant. The land allocations were used to predict carbon densities for 1980–2163 for both scenarios, holding the predicted land allocations at their 2011 levels for each scenario. Holding land allocations at 2011 levels in order to predict the cycle of carbon accumulation (carbon densities) before and after 2011 (1980–2163) was done under the assumptions that: (i) climate, disturbance and management, as well as other environmental characteristics, were the same for the baseline and hypothetical scenarios for 1980–2163; (ii) land allocations for 1980–2010 were the same for both scenarios; and (iii) land allocations for 2011–2163 were different between the two scenarios, but fixed at their respective 2011 levels predicted from the land use model.

To calculate annualized forest carbon sequestration, the carbon densities from the forestland carbon pools were summed (referred to as ‘carbon stock’) and the present value of tonnes sequestered for each county was calculated. Then, the weighted averages of the present values of carbon sequestration were calculated for each county based on the county’s shares of the two tree types and six soil types. (See S6 in the supplementary materials.) This present value of carbon sequestration is not obtained by comparing scenarios, but is a within-scenario weighted average. It is worth noting that distributions of the two tree types vary widely across counties, with oak trees being the dominant species (i.e. 76.6–92.4% oak trees versus 0.6–15.6% loblolly pine trees). Because of the different potentials for carbon sequestration between the tree types (i.e. averages of 1.69 and 1.18 tonnes per hectare, respectively, for loblolly pine and oak trees in the study area), the distribution of the tree types results in different spatial impacts of the tax-based subsidy on county carbon stocks.

Finally, the weighted averages of the present values of carbon sequestration were annualized up to the end of the study period (2163) with a 5% discount rate. (See Table 2 for an example for Loudon County, Tennessee.)

Cost per hectare and quantity of carbon sequestration

The increase in a county’s forestland area resulting from the waived forestland property tax is estimated by the difference in the predicted forestland probabilities between the hypothetical and baseline scenarios times the total county area (e.g. 0.0012 × 63,973 hectares = 76.77 hectares; Loudon County highlighted in Table 3). The county increases in the predicted forestland probabilities are derived from the

Table 2 Annualized carbon sequestration (tonnes per hectare) for the two tree types and six soil types for Loudon County.

	Oak (84.4%)	*Loblolly pine (15.6%)*	*Weighted average across tree types*
Clay loam (24.2%)	1.191	1.744	1.277
Clay (21.5%)	1.229	1.971	1.344
Loam (2.1%)	1.186	1.732	1.272
Sandy clay (52.2%)	1.156	1.534	1.215
Weighted average across soil types	1.181	1.683	1.260

marginal effects of the forestland returns (see Table 4). Those marginal effects imply that a US$1 per hectare in forestland returns increases the share of forestland by 0.45%, while it decreases the shares of pastureland, cropland and other uses by 0.57%, 0.01% and 0.03%, respectively (see Table 4). Conversely, a US$1 per hectare increase in forestland returns increases the predicted urban land share by 0.16%. The marginal effects imply that the increases in forestland net returns by the tax-based subsidy would encourage afforestation mostly of pastureland; however, the same increase would not help mitigate deforestation for urbanization. The afforestation of pastureland is realistically the most feasible type of land use change that can be encouraged by the tax-based subsidy, given that deforestation to pastureland occurred most often among all types of deforestation (i.e. 55%) during 2006–2011.

The increased forestland area was multiplied by the annualized carbon sequestration rate per hectare in order to obtain the additional carbon sequestration due to the county-level tax-based subsidy (e.g. 76.77 hectares × 1.26 carbon tonnes per hectare = 97 carbon tonnes sequestered; Loudon County highlighted in Table 3). The property tax amounts were calculated by multiplying the assessment ratio of forestland, weighted-average property tax rate in 2006 and annualized weighted-average soil expectation value per hectare (0.25 × 0.0182 × US$48.46 per hectare = US$0.22 per hectare) (Table 3). The waived property tax (i.e. cost to the county of the tax-based subsidy) was obtained by multiplying the county's forestland stock by the reduced forestland tax revenue per hectare (6860 hectares × US$0.22 per hectare per year = US$1509 per year) (Table 3). Finally, the county's annualized cost per tonne of supplying carbon sequestration was obtained by dividing the waived property tax by the additional carbon sequestered due to the tax-based subsidy (US$1509 per year/97 carbon tonnes = US$15.56 per carbon tonne) (Table 3).

RESULTS

Marginal effects of land use return

The estimated multinomial logit model correctly predicted 75% of land use allocations. The predictability and its goodness of fit measures (i.e. McFadden's pseudo R^2 of 0.41) verify a reasonably good performance of the model given the limited number of covariates included. The marginal effects of forestland, pastureland, cropland and urban land returns were all positive and significant at the 5% level (hereafter, referred to as 'significant') (Table 4). Specifically, an increase in a land use's own returns by US$1 per hectare increased its share of county land area by: (i) 0.45% for forestland; (ii) 5.79% for pastureland; (iii) 0.001% for cropland; and (iv) 0.005% for urban land. The differences in the marginal effects of different land use returns may be related to differences in the flexibility of land use conversions. For example, the larger marginal effect for pastureland may be related to pastureland being more easily converted to other uses than conversion of the other three land uses (Alig *et al.* 2010). Pastureland involves relatively lower sunk costs than the other land uses (e.g. forestland and urban) (Loehr 2010). Thus, pastureland can be more easily converted to and from other land uses when its own returns change relative to the returns of other land uses.

The cross-marginal effects of returns from pastureland, cropland and urban land on forestland's share were all negative and significant. Decreases in returns for pastureland, cropland and urban land by US$1 per hectare increased the share of forestland by 2.98%, 0.08% and 0.02%, respectively. These findings imply that decreases in the returns from the other land uses relative to the returns from forestland increase the probability of forestland being chosen as the utility-maximizing land use.

County-level costs for supplying carbon sequestration

Table 3 presents the costs per carbon tonne of supplying county-level forest carbon sequestration for the 18 counties in ascending order (US$15.56–US$563.58 per carbon tonne, column I) and the relevant values used to calculate them. The broad range of costs is due to the variation in: (i) the waived property tax (US$1593–US$69,937, column C), which is multiplied by dollar amounts of property taxes waived per hectare per year (US$0.12–US$0.86, column A) and forestland stocks (6860–112,586 hectares, column B); and (ii) total carbon sequestration (42–426 carbon tonnes per year, column H), which is multiplied by changes in the predicted probabilities of choosing forestland due to changes in forestland returns (0.06–0.26%, column D), total county areas (45,584–169,126 hectares, column E) and average forest carbon sequestration rates (1.19–1.33 carbon tonnes per hectare, column G).

Table 3 County-level costs of supplying carbon sequestration due to tax-based subsidies at mean forestland returns for 18 counties. The rows for Loudon and Bell counties are in bold because the comparison between these two counties is discussed in the main text.

County	*Cost*			*Supply of carbon sequestration*					
	Increased return (reduced tax revenue)	*Forestland stock*	*Waived property tax*	*Change in predicted probabilities*	*Total county area*	*Increased forestland*	*Carbon sequestration rate*	*Total carbon sequestration*	*Annualized cost of carbon sequestration*
	A ($/hectare/year)	*B (hectares)*	*C = A × B ($/year)*	*D (%)*	*E (hectares)*	*F = D × E (hectare)*	*G (carbon tonnes/hectare/year)*	*H = F × G (carbon tonnes/year)*	*I = C / H ($/carbon tonne/year)*
Loudon	**0.22**	**6860**	**1509**	**0.12**	**63,973**	**76.77**	**1.26**	**97**	**15.56**
Monroe	0.12	43,687	5242	0.07	169,126	118.39	1.31	155	33.82
Hamblen	0.17	10,984	1867	0.08	45,584	36.47	1.24	45	41.49
Jefferson	0.27	27,413	7402	0.17	81,326	138.25	1.26	174	42.54
Roane	0.35	56,615	19,815	0.22	102,305	225.07	1.21	273	72.58
Morgan	0.37	80,132	29,649	0.26	135,197	351.51	1.21	426	69.60
Knox	0.47	39,528	18,578	0.14	136,233	190.73	1.26	240	77.41
Cocke	0.30	81,865	24,560	0.20	114,737	229.47	1.26	289	84.98
Blount	0.27	55,913	15,097	0.08	146,852	117.48	1.33	157	96.16
Grainger	0.32	47,649	15,247	0.17	78,218	132.97	1.21	161	94.71
Union	0.20	46,769	9354	0.11	63,973	70.37	1.19	83	112.70
Claiborne	0.20	83,502	16,700	0.09	114,478	103.03	1.19	122	136.89
Sevier	0.17	104,844	17,823	0.07	154,622	108.24	1.28	139	128.22
Anderson	0.47	63,902	30,034	0.18	89,355	160.84	1.19	191	157.25
Scott	0.37	112,586	41,657	0.15	138,046	207.07	1.19	246	169.34
Campbell	0.25	108,800	27,200	0.08	128,982	103.19	1.19	122	222.95
Hancock	0.22	52,674	11,588	0.06	58,016	34.81	1.21	42	275.90
Bell	**0.86**	**79,950**	**68,757**	**0.11**	**93,499**	**102.85**	**1.19**	**122**	**563.58**

We find that the cost per carbon tonne sequestered (column I in Table 3) is lower if total carbon sequestration (column H) is higher and waived property tax (column C) is lower. The correlation coefficient between total carbon sequestration and waived property tax is positive and significant across counties. This finding suggests that higher total carbon sequestration benefits are achievable only at a higher cost of waived property tax; however, there are candidate counties with potential for better cost efficiencies.

The change in the probability of choosing forestland due to a change in forestland returns (column D in Table 3) is the major factor determining the costs of supplying county-level forest carbon sequestration, because the other factors (columns A, B, E and G) are determined by county characteristics. Thus, the difference between the predicted probabilities of the hypothetical and baseline scenarios is the driving force in determining county-level costs of supplying carbon sequestration. Its importance is illustrated by comparing the counties with the lowest and highest annualized costs per carbon tonne (Loudon and Bell Counties, respectively) (Table 3). The same increase of forestland net return increases the predicted probability of choosing forestland more for Loudon County than for Bell County at each county's mean forestland net return (Fig. 3), because the marginal effect is greater at Loudon County's lower mean forestland net return (i.e. US$49.00/hectare/year) than Bell County's higher mean net return (i.e. US$103.75/hectare/year), all else being constant. Thus, Loudon County would achieve a lower cost of carbon sequestration than Bell County for the same increase of net returns from forestland through a tax-based subsidy, all other county characteristics being constant.

Table 3 shows that the annualized costs per carbon tonne sequestered are within (seven counties), lower (one county) and higher (ten counties) than the range found in the previous literature for US forest carbon sequestration (i.e. US$30–US$90 per carbon tonne) (Stavins & Richard 2005). This finding implies that federal agencies can target selected counties to adopt the county-level tax-based subsidy approach based on their cost efficiency per tonne of carbon sequestration. For example, if a budget of US$150,000 were allocated to promote carbon sequestration in the 18 counties, the relevant federal agencies could target the 11 least-cost counties (Loudon, Monroe, Hamblen, Jefferson, Roane, Morgan, Knox, Cocke, Blount, Grainger and Union Counties) for a total expense of US$148,151 in order to achieve 2100 tonnes of carbon sequestration. This total cost is *c.* 40% of the total cost of implementing the tax-based subsidy approach in all 18 counties. The average cost per tonne of sequestering 2100 tonnes of carbon would be US$70.63 per tonne (= US$148,322/2100 tonnes). Given the same budget of US$150,000, if the performance-based payment approach (i.e. a fixed incentive per tonne of sequestered carbon) were adopted without differentiating costs between counties, the average cost of sequestering 1127 tonnes of carbon would be US$133.09 per tonne (= US$149,996/1127 tonnes).

Table 4 Parameter estimates (PEs) and marginal effects (MEs (%)) from the multinomial logit model for land use allocations (standard errors in parentheses). The category of other uses was used as the reference group. * Statistical significance at the 5% level.

	Forestland		*Pastureland*		*Cropland*		*Urban land*		*Other uses*
Variable	*PE*	*ME*	*PE*	*ME*	*PE*	*ME*	*PE*	*ME*	*ME*
Returns from forestland	0.038* (0.003)	0.451* (0.183)	–0.089* (0.003)	–0.574* (0.019)	–0.887* (0.191)	–0.012* (0.003)	0.036* (0.004)	0.162* (0.018)	–0.027* (0.010)
Returns from pastureland	0.490* (0.837)	–2.975* (1.456)	0.849* (0.833)	5.790* (0.218)	0.211 (0.547)	–0.056 (0.069)	0.517* (0.867)	–0.662* (0.174)	–2.10* (0.244)
Returns from cropland	–0.007* (0.001)	–0.078* (0.000)	–0.001 (0.003)	0.084* (0.000)	0.001* (0.001)	0.001* (0.000)	–0.005* (0.000)	–0.001* (0.000)	0.001* (0.000)
Returns from urban land	–0.005 (0.003)	–0.023* (0.000)	0.001 (0.002)	–0.022* (0.000)	–0.001 (0.002)	–0.001 (0.000)	0.009* (0.000)	0.005* (0.000)	–0.005* (0.000)
Elevation	0.023* (0.001)	0.003* (0.001)	0.022* (0.001)	0.311* (0.003)	0.001 (0.004)	–0.002* (0.000)	0.019* (0.001)	–0.003 (0.002)	–0.064* (0.002)
Slope	0.898* (0.017)	6.826* (0.393)	0.320* (0.016)	–4.461* (0.061)	0.350* (0.074)	–0.004 (0.007)	0.267* (0.018)	–0.011* (0.000)	–1.251* (0.044)
Year dummy	2.364* (0.430)	–10.337* (1.452)	4.323* (0.427)	25.043* (0.812)	1.261 (2.821)	–0.161 (0.674)	2.296* (0.445)	–2.403* (1.174)	–12.142* (2.481)

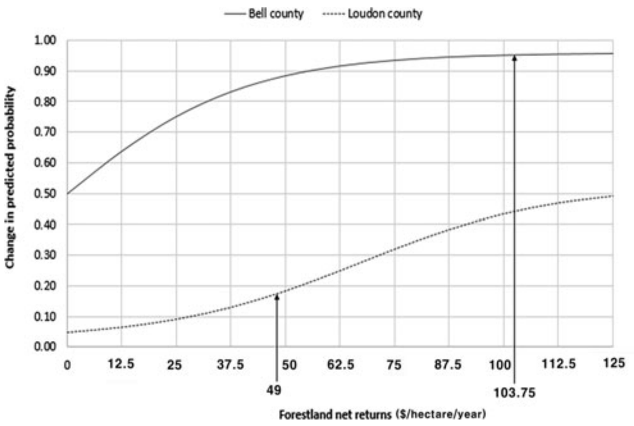


Figure 3 Changes in predicted probabilities of choosing forestland at different forestland returns for Loudon and Bell Counties: $49.00/hectare/year and $103.75/hectare/year are, respectively, Loudon and Bell Counties' mean forestland net returns, as discussed in the main text.

DISCUSSION

We show that an increase in returns from forestland by waiving the property tax on forestland increases the share of forestland within a county, which in turn increases the accumulation of carbon in the forest ecosystem. These results suggest that waiving the property tax on forestland provides incentive for landowners to afforest non-forested land and to sustain forests that are at risk of deforestation, and thus the county-level tax-based approach is viable. The annualized costs of implementing the county-level tax-based subsidy approach to the 18 county governments range between US$15.56 and US$563.58 per carbon tonne. This broad range of costs is mainly due to variations in total carbon sequestration and waived property tax. Of all the cost-determining factors, the change in the probability of choosing forestland due to a change in forestland returns is the only driving force that can determine the costs of supplying county-level forest carbon sequestration through a forestland property tax subsidy.

Our county-level estimates can be used similarly to the references that are used to aid decision making for offering enrolment in existing payment for ecosystem services programmes around the world (Hyde *et al.* 2003; Pagiola 2005; Schomers & Matzdorf 2013). For example, relevant federal agencies can use the county-level estimates of carbon sequestration rates and annualized costs per tonne of carbon sequestration to target selected counties for better cost efficiency when adopting the county-level tax-based subsidy approach. Comparable to the Environmental Benefits Index used in the conservation reserve programme (CRP) decision-making process, our county-level carbon sequestration rates and annualized costs per tonne of carbon sequestration can help rank counties' requests to enrol in such a tax-based subsidy programme. Once the target counties are selected, returns from forestland can be used to determine the bid cap on how much property tax can be waived for each county for an available budget similar to the maximum acceptable bid (or bid cap) for CRP, which is based on the soil rental rate – an estimate of the parcel's agricultural rental value set by the United States Department of Agriculture Farm Service Agency (Hellerstein *et al.* 2015).

In practice, however, tax uniformity may be required within a jurisdiction, and state legislatures may restrict tax codes in counties (e.g. 'uniformity clauses' and the 'Dillon's Rule', respectively, in the US Constitution) (Fisher 1997; Schoettle 2003). Apart from these potential obstacles, various income tax deductions have been claimed for land conservation such as conservation easements, which are voluntary, legally binding agreements that limit certain types of uses or prevent development from taking place on the land in perpetuity (Pidot 2005; Richardson 2010; Eagle 2011). Thus, applying the option of offering property tax subsidies at the county level to individual forestland owners may be considered an alternative to incentive payment programmes.

CONCLUSION

We found a broad range of county-level costs of implementing the tax-based subsidy approach. The demonstrated county-level spatial heterogeneity in the effects of adopting the county-level tax-based subsidy approach serves as an empirically informed knowledge base for policy-makers to utilize in evaluating trade-offs among various forest carbon incentive payment programmes for any given area. Specifically, the county-level estimates of carbon sequestration rates and annualized costs per tonne of carbon sequestration can be used by relevant federal agencies (or state agencies, for that matter) to target selected counties. The selected county governments can anticipate the maximum changes in forestland and forest carbon sequestration that are attainable within their boundaries at their respective costs per tonne of carbon sequestration. Given the information that is available to the selected county governments, the county governments can make decisions on whether to participate in the tax-based subsidy programme on this basis. If a county government decides to participate in the programme, the returns from forestland can be used as a reference point for eliciting offers to subsidize the county's cost of implementing the programme. By framing the funding decision as a reverse auction, such as the CRP, we resolve asymmetric information in our county-level estimates, and thus competition between participant counties can improve cost-effectiveness.

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Supplementary Material

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