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Land-based greenhouse gas emission offset and leakage discounting

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ABSTRACT

This paper examines leakage from agricultural greenhouse gas reduction programs stimulated by reductions in regional commodity supply. This paper develops an extension of the leakage discount formula in Murray et al. (2004) that incorporates changes in input (land) usage rather than product output (crop or forest product quantity). Additionally the leakage discount developed here allows for land conversion and production replacement involving multiple alternative uses. In an empirical application in the Southeast Texas we compute leakage discounts of 14.8% for the conversion of rice to no-till sorghum and 14.9% for rice to pasture program. Most of the sources of GHG offset leakage come from conversions of cotton to rice and pasture to rice in the other regions.

1. Introduction

Land-based greenhouse gas (GHG) offsets developed through afforestation, reforestation, crop mix alteration, bioenergy production and other agricultural and forestry based mitigation strategies can be a relatively inexpensive option[1] for reducing greenhouse gas (GHG) emissions (Adams et al., 1993; Antle et al., 2007; IPCC WGIII, 2014; Lewandrowski et al., 2004; Lubowski et al., 2006; McCarl and Schneider, 2001; Murray et al, 2005; Park and Hardie, 1995; Plantinga et al., 1999; Stavins, 1999). Land-based GHG offsets may be subject to "discounts" due to concerns commonly called leakage (Murray et al., 2004), additionality (Chomitz, 1998), permanence (Kim et al., 2008), and uncertainty (Kim and McCarl, 2009; Smith et al., 2007). Here we focus on leakage.

Leakage results when a GHG offset program in a region stimulates an increase in GHG emissions in other regions (Murray et al., 2004). In particular, when a regional offset program is implemented, it potentially reduces the supply of agricultural and forestry products in the target region but other regions react to replace the diminished supply. The replacement of the lost supply involves altering economic activities in the other regions and this can potentially result in increased GHG emissions. To the extent that this happens, the GHG offset program "leaks" making the net global effect smaller than the regional effect. This means that the GHG offset gains in the implementing region likely overstate the gains to society and possibly should be discounted to account for leakage.

The leakage effect depends on market characteristics including the relative elasticity of demand and supply of the commodities involved. Inelastic supply shrinks the leakage effect and inelastic demand increases the leakage effect (Murray et al., 2004). Previous results indicate that leakage varies by cases. Some cases exist where leakage is likely to be small, for example, Murray et al. (2005) estimate leakage below 10% for programs that involve tillage conversion. But, in contrast, other estimates show leakage as large as 90% from forest programs (Murray et al., 2004). Additionally arguments have been made in the case of bioenergy programs that leakage can lead to negative overall results (Searchinger et al., 2008).

Other empirical studies on leakage can be found in the context of investment crowding, agricultural conservation programs, crop commodity diversion, and bioenergy. Lee et al. (1992) examine U.S. tree planting programs and find a crowding-out effect for government-subsidized tree planting efforts with gains in the target region offset by losses elsewhere. Wu (2000) examines the Conservation Reserve Program (CRP) and finds that roughly 20% of the acres diverted from production were replaced by other acreages, with 9 to 14% of the environmental benefits offset.[2] Brooks et al. (1992) and Hoag et al. (1993) investigate the leakage effect

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[1] Land-based GHG mitigation may have a higher opportunity cost in developed countries. According to Torres et al. (2010), agroforestry carbon sequestration cost exhibits a U-shaped cost curve when transaction and opportunity costs of agricultural practices are included. Chcho et al. (2005) asserts that land-use change and forestry projects may be constrained by high transaction costs especially for projects involving smallholders in developing countries.

[2] Roberts and Bucholtz (2005, 2006) argue that Wu (2000) likely provides overestimates due to endogeneity and omitted variable biases.

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in U.S. crop commodity programs and provide evidence of offsetting responses by producers. Searchinger et al. (2008) and Hertel et al. (2010) look at how US ethanol policies affect global land use and find GHG emission leakage.

Murray et al. (2004) develop a leakage discount formula that involves market parameters such as price elasticities, and substitutability between commodities. This paper extends the Murray et al. (2004) analysis in two important ways. First, an alternative formula for a leakage discount is developed that is based on changes in land usage rather than product output (crop or forest product quantity). And second, the formula allows for land conversion from and to multiple alternative uses accommodating more complex situations.[3]

2. Modeling Leakage for Regional Agricultural Land-Based GHG Emission Offset Program

Suppose there are two otherwise identical regions (*prg* and *elw*) that produce all of a commodity with an offset project implemented in region *prg* and no project implemented in *elw*. Suppose the regional production is $S_{prg} = S_{prg}(p, \mathbf{w}_{prg})$ and $S_{elw} = S_{elw}(p, \mathbf{w}_{elw})$. Note that we assume that *all* the producers in the *prg* area participate the GHG offset program.[4] In the regional supply equations (S_{prg} and S_{elw}) p represents the price of the commodity and $\mathbf{w}$ the associated input–price vector. Assume that the aggregate demand function for the commodity is $D = D(p, \mathbf{z})$, where D is the quantity demanded, and $\mathbf{z}$ is a vector of demand shifters such as consumers' income, substitute prices, etc.

Market equilibrium equates summed supply from both regions with demand:

$$S_{prg}\left(p^*, \mathbf{w}_{prg}\right) + S_{elw}\left(p^*, \mathbf{w}_{elw}\right) = D(p^*, \mathbf{z}), \tag{1}$$

where the equilibrium price is represented as p^*.

Following Murray et al. (2004) we consider the excess demand, *ED*., that meets the supply from area *elw*, which is the difference between total demand and area *prg* supply. The excess demand facing area *elw* can be defined as follows:

$$ED\left(p, \mathbf{z}, \mathbf{w}_{prg}\right) = D(p, \mathbf{z}) - S_{prg}\left(p, \mathbf{w}_{prg}\right). \tag{2}$$

Inserting Eq. (2) into Eq. (1), then the equilibrium for area *elw* can be found by solving $S_{elw}(p^*, \mathbf{w}_{elw}) = ED(p^*, \mathbf{z}, \mathbf{w}_{prg})$.

This market is illustrated in Fig. 1, where the excess demand function facing *elw*, *ED*, is the difference between the total demand functio*D* in panel (a) and the program region supply function S_{prg} in panel (b). Prior to implementing the regional program (superscript 0), the equilibrium price is p^0 at $S^0(=S_{prg} + S_{elw}) = D$, the amount produced in area *prg* is Q^0_{prg}, in area *elw* is Q^0_{elw}, and the total amount produced and consumed is $Q^0 = Q^0_{prg} + Q^0_{elw}$. Correspondingly, the land usage for the commodity in the regional program area is L^0_{prg} and in the outside area *elw* is L^0_{elw} from the production function in Panel (d) and (e). Total land usage is $L^0 = L^0_{prg} + L^0_{elw}$.

Suppose that the GHG offset program induces *prg* producers to discontinue commodity production and plant another crop that increases carbon sequestration. Supply from the regional program area *prg* will decrease (in this extreme case to zero) as shown in panel (b) of Fig. 1, and the excess demand faced by *elw* producers shifts outward from ED^0 to ED^1 stimulated by S_{prg} going to zero. The outward shift in the excess demand function facing *elw* disrupts the initial equilibrium. In order for the market to clear again, the output price will rise and will induce more supply into the market from additional *elw* production. The new equilibrium is reached at (p^1, Q^1) and $Q^1 = Q^1_{elw} > Q^0_{elw}$. At the new equilibrium, the land usage in area *elw* is L^1_{elw} as depicted in panel (d) of Fig. 1 and shows an increase. That increase raises the potential for leakage.

The leakage effect under the assumption of equal emissions per acre in both regions is illustrated in Fig. 2. The GHG emission offset in the regional program area is GHG^0 but the increase in land usage in the *elw* area increases their GHG emission offset by GHG^1. The leakage can be defined as the ratio of GHG^1 to GHG^0 in Fig. 2.

3. Derivation of Leakage Discount

3.1. Leakage for a Single Land Use

First we consider a single land use case. Let k be the commodity that experiences a production decline when the GHG offset program is implemented and k' an alternative commodity that increases. The quantity of land in the program area *prg* for crop k is denoted by $L^0_{k,prg}$ and thus the total amount of GHG emission reduction under the program is given by $L^0_{k,prg} \cdot sr_{k,prg}$, where $sr_{k,prg}$ is the per-acre net-GHG emission reduction rate in *prg* when producing crop k. Let changes in area *elw*'s quantity of land allocated to crop k be denoted as $\Delta L_{k,elw}$ which is defined as $\Delta L_{k,elw} = L^1_{k,elw} - L^0_{k,elw}$ in Figs. 1 and 2. Thus the amount of GHG emission leaked outside of the regional program region is $\Delta L_{k,elw} \cdot sr_{k,elw}$.

In addition, the regional GHG offset program increases the crop k' production in *prg* and we assume that market principles lead the *elw* region to reduce their production of crop k' due to a decrease in market prices (i.e., the excess demand for crop k' curve shifts inward stimulating a production reduction in *elw*). In this case, we define leakage as follows:

$$LEAK(\%) = \frac{\Delta L_{k,elw} \cdot sr_{k,elw} + \Delta L_{k',elw} \cdot sr_{k',elw}}{L^0_{k,prg} \cdot sr_{k,prg}} \times 100. \tag{3}$$

The denominator in Eq. (3) is the total amount of GHG emission offset created by the regional program in the *prg* area, and the numerator is the sum of the amount of GHG emission change in the other region, *elw*. In order to calculate this leakage, we need estimates of $\Delta L_{j,elw}$ and $sr_{j,elw}$ $(j = k, k')$ which we now derive. The size of the regional program area, $L^0_{k,prg}$, is assumed known at the outset.

Suppose the output elasticity of land, E^L, is defined as,

$$E^L = \frac{\Delta Q^S}{\Delta L} \cdot \frac{L^0}{Q^0}, \tag{4}$$

where ΔQ^S is the change in quantity supplied (produced) associated with a change in land area ΔL. Defining this for region *elw* from Eq. (4), $\Delta L_{j,elw}$ $(j = k, k')$ is,

$$\Delta L_{j,elw} = \frac{\Delta Q^S_{j,elw}}{E^L_j} \cdot \frac{L^0_{j,elw}}{Q^0_{j,elw}} \left(j = k, k'\right), \tag{5}$$

where the subscript j is suppressed in the interest of simpler notation for now. Initial supply from the region *elw* is Q^0_{elw}, with initial land use being L^0_{elw}, and the output elasticity of land, E^L. All of these terms are assumed observable except ΔQ^S_{elw}. This supply change can be found in the market.

[3] Land conversion to multiple uses will be estimated using a Markovian land transition matrix as explained in later sections. To make it clear here, the Markovian land transition captures only the historical land use change and thus estimated land conversion for the leakage calculation is the *expected* change based on *historical* land use change.

[4] A regional program refers to an activity occurring on a well-defined parcel of land like a county or state. Farmers opt in to offsets projects voluntarily and thus any region would presumably have a mosaic of farms that have projects and those that do not. This means that leakage can occur within a (regional program) region. In this paper for simplicity all the farms in the program region are assumed to participate in the GHG offset program.