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An analysis of the feasibility of carbon management policies as a mechanism to influence water conservation using optimization methods

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ABSTRACT

Studies of how carbon reduction policies would affect agricultural production have found that there is a connection between carbon emissions and irrigation. Using county level data we develop an optimization model that accounts for the gross carbon emitted during the production process to evaluate how carbon reducing policies applied to agriculture would affect the choices of what to plant and how much to irrigate by producers on the Texas High Plains. Carbon emissions were calculated using carbon equivalent (CE) calculations developed by researchers at the University of Arkansas. Carbon reduction was achieved in the model through a constraint, a tax, or a subsidy. Reducing carbon emissions by 15% resulted in a significant reduction in the amount of water applied to a crop; however, planted acreage changed very little due to a lack of feasible alternative crops. The results show that applying carbon restrictions to agriculture may have important implications for production choices in areas that depend on groundwater resources for agricultural production.

1. Introduction

Over the past century, the amount of green house gases, such as carbon dioxide, emitted by humans has increased exponentially. Recently, the concern about the effect that man-made carbon emissions have on the earth has led to concerns about how we interact with the environment. The predicted effects of large scale changes in the earth's climate are many and include changes in water availability, ecosystem structures, agricultural productivity, and sea level, as well as various impacts on the human population (United Nations, 2010). While there is little debate that global CO_2 levels are rising and the climate is changing, there is uncertainty about the severity of the changes listed above (McKibben and Wilcoxen, 2002); as such, there is an ongoing debate about whether or not anything should be done to change how we live our lives in order to mitigate the problem. This debate, however, has not prevented governments from attempting to curb the emission of carbon by humans.

In the United States, these efforts include the proposal of the American Clean Energy and Security Act of 2009 (the "Waxman-Markey" bill) in the House of Representatives. This bill is important not only for its proposed changes in how the nation deals with carbon emissions, such as setting up a cap and trade scheme for carbon regulation, but also for the fact that it passed in the House before stalling in the Senate. No other bill regulating carbon emissions in America had gone so far through the legislative process. Along with this legislative effort, the Environmental Protection Agency (EPA) claims that it already has the right to regulate carbon emissions via the Clean Air Act and has created new regulations regarding carbon emissions; although the EPA's authority to do so has been challenged in federal court.

The willingness of policymakers to confront the issue of climate change in the United States has drawn the interest of researchers and industries alike. At the heart of this interest lie the additional costs and benefits to society implied by climate change policy. In the affected markets, producers and consumers are concerned with the economic costs of CO_2 emissions regulations that reduce production levels. Outside of these markets, the focus is on the additional benefits related to limiting CO_2 emissions such as the mitigation of climate change, and other ancillary effects. These secondary effects include reductions in costs, for example health damages, related to greenhouse gas emissions (e.g., Ekins, 1996;

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Hourcade et al., 2001; Burtraw et al., 2003; Riekkola et al., 2011) as well as negative effects such as an increase in the emissions related to diesel fuel when it is substituted for gasoline (Riekkola et al., 2011).

Previous studies show that accounting for ancillary benefits can substantially reduce the net economic cost of climate change policies (e.g., Boyd et al., 1995; Repetto and Austin, 1997; Van Vuuren et al. 2006; Riekkola et al., 2011). The implication of these results to the study of CO_2 emissions regulation is that these ancillary benefits should be accounted for in the net economic costs of the policy itself.

While neither Waxman-Markey nor EPA regulations as currently written and implemented address agricultural production directly, there is a body of research related to the effect such policies would affect crop production in the United States. For example, Nalley, et al. (2011) develops a method by which carbon equivalent (CE) emissions could be calculated at the farm level using Life Cycle Analysis. Later studies have used these calculations in combination optimization methods to study how producers would react to the additional revenue from trading carbon credits in a carbon offset market, such as the type of market that would have been established for other industries by Waxman-Markey (Nalley and Popp, 2010; Popp et al., 2011). Scenarios that calculated both gross and net carbon emissions were considered and produced different results.

These studies showed that whether gross or net carbon emissions are considered is important to who benefits from trading carbon credits in a carbon offset market. Areas in the study that were high emitters of carbon were also high sequesterers of carbon; thus, when only gross carbon emissions are considered in emission calculations these areas do not benefit from trading in an offset market, but when net emissions are considered these areas can benefit from selling carbon credits. The same is true of certain crops, such as corn, that were found to be both high emitters and sequesterers of carbon.

Studies of how carbon reduction policies would affect agricultural production have also found that there is a connection between carbon emissions and irrigation. The CE emissions calculated by Nalley et al. (2011) show that center pivot irrigation is a large contributor to carbon emissions in agriculture due to the energy involved in pumping water from the ground. Wright and Hudson (2011) estimate the impact on farmer's net revenue on the Texas High Plains of a 95% and 85% reduction on carbon emissions compared to a baseline scenario with no constraint on emissions. The study calculated carbon in a manner similar to that of Popp et al., but allows for the amount of water used in the production process to vary as a choice variable in the model. The result is that the choices of what crop to plant and how many acres to plant tended to remain constant while the number of acre-inches applied to a crop (and the resulting yield) is reduced to meet the constraint.

The connection between carbon reduction and water use reduction found by Wright and Hudson implies that, in agriculture, a carbon reduction policy is a restriction on water use. In light of the recent debate about how to regulate the use of the Ogallala Aquifer by landowners on the Texas High Plains, this result poses an interesting question. Could water conservation be realized through carbon policy? If so, then the conservation of an important resource to this area might be considered an ancillary benefit much like those discussed above.

The primary goal of this paper is to further the research on the regional effects of climate change policies on U.S. agricultural production by examining the effect of both a tax on carbon emissions and a subsidy for emissions reduction on the Texas High Plains. Specifically, optimization methods will be used to determine what level of tax or subsidy is necessary to influence a reduction in carbon emissions, and to determine the effect these policies have on farmers' net revenue, crop and acreage choices, and water usage. The tax and subsidy will be applied on a county by county basis as well as on a regional basis to determine if there are any significant differences in acreage, water use, and carbon reduction between a location specific or aggregate policy.

In addition, this paper represents a contribution to the literature on the ancillary benefits of climate change policies. Previous studies have focused on the extra benefits related to reductions in air pollution. Measuring the benefits to resource conservation stemming from climate change policy results is an avenue for further research on this topic.[2] Furthermore, the management of water for agricultural use is an issue faced by agricultural producers across the globe, so our results may have implications beyond West Texas to other regions of the world as well.

2. Conceptual framework

Conceptually, the connection between carbon emissions and irrigation can be illustrated through a simple profit maximization problem. Assume a risk neutral producer in a perfectly competitive environment plants a single crop, y, that is produced using water as the single variable input, x, and other fixed inputs. The profit function is

$$\pi = py - rx - c \tag{1}$$

where

$p =$ the price of the crop,
$y = y(x)$, crop yield as a function of the amount of water used,[3]
$r =$ the price of the variable input, and
$c =$ the fixed cost associated with production.

Thus, profit is a function of water use, and the amount of water that maximizes profit, x^*, is found by solving for x using the first order condition,

$$py' - r = 0 \tag{2}$$

or when the marginal value product equals the variable input cost.

During the production process, carbon is emitted and emissions, E, vary positively with the amount of water used. This function can be expressed as

$$E = E(x), \tag{3}$$

and the amount of carbon emitted at the profit maximizing level of production is $E^* = E(x^*)$. Now assume that a limit is placed on how much carbon can be emitted, and the producer is constrained to some fraction of his optimal level of carbon emissions so that $\overline{E} = aE(x^*)$ where $0 \le a \le 1$. Because $\overline{E} < E^*$, and E varies positively with x, it follows that there must be some $\overline{x} < x^*$ that satisfies the constraint. Producers will use water up to the amount $\overline{x}$, which results in a lower yield and total profit than in the unconstrained case.

If carbon is limited by means of a tax instead of a constraint, the producer's objective function changes to reflect the tax so that

[2] We would like to thank the reviewer for pointing this out.

[3] Normally, x would be a vector of inputs. We restrict x to the single variable case of water because, over the range of water applied to crops in our study area, there is very little substitution of other inputs observed. For this reason, the benefit of developing county level production functions that allowed for substitution between inputs is less than the cost in terms of collecting and processing the necessary information.