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Spatio-temporal association of fossil fuel CO_2 emissions from crop production across US counties

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ABSTRACT

This article offers a spatio-temporal analysis of the distribution of CO_2 emissions, the main cause for greenhouse gases, due to agricultural activities across US counties. Based on a novel database, we investigate how crop production output (measured in carbon) relates to CO_2 emitted in the production and transportation process of the inputs needed for crop production. Various spatial statistics are used to highlight the clusters of counties with similarities in the levels and growth of output per area, input per area and productivity. At the same time, significant levels of heterogeneity are highlighted for all variables. A decomposition method allows us to uncover that the origin of interregional differences in productivity differs across the clusters of counties. Our results indicate that future mitigation policies should not fail to recognize interregional differences in the location, spatial extent and origin of carbon emissions due to the crop production process.

1. Introduction

Agriculture has an important role in the mitigation of greenhouse gases (GHGs) as a carbon sink, but it is also a source of GHGs. Indeed, significant amounts of the major GHGs—nitrous oxide (N_2O), methane (CH_4) and carbon dioxide (CO_2)—are released to and/or removed from the atmosphere because of agricultural activity (Paustian et al., 2004). Agriculture has an important role in the mitigation of greenhouse gases (GHGs) as a carbon sink, but it is also a source of GHGs. Indeed, significant amounts of the major GHGs—methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2)—are released to and/or removed from the atmosphere because of agricultural activity (Paustian et al., 2004). According to Smith et al. (2008), agriculture accounts for 52 and 84% of global anthropogenic CH_4 and N_2O emissions respectively. Although the net emission of CO_2 is small, it is mostly due to on-farm energy use and to the manufacture and transport of agricultural products (Snyder et al., 2009). Therefore, efforts to mitigate the role of agriculture in GHG emissions have a significant importance in the climate change policies.

Therefore, efforts to mitigate the role of agriculture in GHG emissions have a significant importance in the climate change policies.

While a significant amount of atmospheric carbon is fixed by the soil and crops in croplands (Hicke et al., 2004), it is respired back to the atmosphere as the harvested biomass is consumed by humans and domesticated animals (Ciais et al., 2007; West et al., 2009). Additionally, CO_2 emissions are generated in the production or manipulation of the inputs needed in the agricultural production process. Those inputs are fossil fuel use for the operation of machinery, heating, crop drying, cultivation, planting, harvesting, irrigation, the manufacturing of fertilizers and pesticides as well as the transport and electricity used to carry and produce them (Paustian et al., 1998; West and Marland, 2002). While terrestrial carbon stocks are both a sink and a source of carbon, fossil fuel used in the production, operation and hauling of the above inputs is only a source of atmospheric CO_2 emission.

West et al. (2010) indicate that fossil fuel used in agricultural production released more CO_2 to the atmosphere than what was sequestered in soil in the United States for the year 2004. In addition, net CO_2 emissions, the difference between source and sinks, vary spatially. Indeed, net CO_2 emissions are governed by factors such as climate and soil characteristics (Polsky and Easterling, 2001; Thornton et al., 2009), crop production practices, and land-use change (Nalley et al., 2011; Nelson et al., 2009; Paustian et al., 1998; Robertson et al., 2000; Smith et al., 2008; West et al., 2010). Geographical differences in the distribution of these variables influence on-going efforts to reduce emissions, enhance removals and

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avoid (or displace) emissions (Smith et al., 2008). As a result, even if it is well known that CO_2 emissions has a global climatic impact, understanding its local distribution and highlighting the nature and extent of its spatial dependence are still necessary steps to accurately estimate GHG mitigation potential and avoid misleading inference.

In spite of the above contributions, little is known about how CO_2 emissions due to agriculture vary over space and time in the US. Indeed, previous literature on the US only focuses on a specific region, not the entire set of counties. We fill this gap by using the data created by the Carbon Dioxide Information Analysis Center (CDIAC), and we identify the spatial patterns in the distribution of fossil fuel CO_2 emissions due to agriculture across the US counties over 1990–2008. More precisely, we use a statistical approach to investigate the spatio-temporal distribution of crop productivity measured in carbon units per fossil fuel CO_2 emission. This allows us to identify the counties that display greater levels and growth of crop related CO_2 emissions and to understand if the source of their differences lies in the output (type and quantity of crop produced) or in its input requirements. If any meaningful spatial pattern or temporal trend is identified in a specific county or a group of counties, it would be helpful for policy makers willing to increase the efficiency of crop production to find out where they should focus their efforts on increasing crop production or reducing the input requirement.

While a handful of contributions has already worked with the dataset of the National Agricultural Statistics Service (NASS) of the U.S. Department of Agriculture (USDA), relying on data related to the net primary production (NPP), or photosynthetic carbon uptake by annual crops, to explore the spatial distribution of CO_2 emissions across the US (Hicke et al., 2004; Nelson et al., 2009; West et al., 2010), none of them investigate the relative role of CO_2 emissions due to crop output vs. crop input and all of them rely on choropleth maps only, which may lead to erroneous conclusions as such maps are very sensitive to the number of intervals selected to represent the variable of interest (Chakir et al., 2011; Ezcurra et al., 2008). In addition, choropleth maps do not allow us to discover patterns nor significance levels of spatial association and spatial heterogeneity.

As a result, this paper proposes the first Exploratory Spatial Data Analysis (ESDA) of the distribution of nation-wide crop productivity levels and growth (in carbon/CO_2 unit) in the US. Previous ESDAs related to this topic focused on Norway (Horabik and Nahorski, 2010) or France (Chakir et al., 2011). In addition, we offer a method that decomposes the spatial variation in carbon crop productivity into the share attributable to regional differentials in crop production vs. CO_2 emitted by the use, production and transportation of inputs necessary in the crop production process. While this method does not imply causality, it still helps pinpoint the factor driving spatial differences in CO_2 emissions levels and growth where there is no well-established theory; hence it is informative to the mitigation process. Note that our approach measures the role of spillover effects also which is not always done when investigating the regional evolution of U.S. CO_2 emissions (Baldwin and Sue Wing, 2013).

The remainder of the paper is organized as follows: Section 2 describes the data, their source and basic statistics. In Section 3, we perform the ESDA of the distribution of carbon embedded in produced crop (output), geogenic CO_2 emissions due to the use of fossil fuel for crop production (input), and the crop productivity measured as the ratio of the previous two elements (output/input). Section 4 proposes a decomposition technique to identify the source of the regional differences in output-input levels and growth. Finally, Section 5 concludes with a summary of findings and some closing remarks.

2. Data description

The datasets of this study comes from the Carbon Dioxide Information Analysis Center (CDIAC). They offer county level estimates of (1) total crop production (http://cdiac.ornl.gov/carbonmanagement/cropcarbon/) and (2) the associated amount of fossil fuel CO_2 emissions across US counties (http://cdiac.ornl.gov/carbonmanagement/cropfossilemissions/).

According to the author of the first dataset (West, 2011), total crop production per county (in units of mega grams of carbon per year) has been calculated by integrating the amount of carbon in each type of crop within each county, following the statistical method described in Hicke et al. (2004), Hicke and Lobell (2004), and Prince et al. (2001). As Hicke et al. (2004) claim, this approach presents the advantage of allowing us to compare and aggregate production across different crop types under a common unit – carbon. It is important to note that this unit of measurement does not indicate pollution due to the production of crop. Pollution is measured in terms of carbon for CO_2 estimates in the denominator that captures the use, the fabrication and transportation of inputs needed in the production of crops. The CO_2 emissions are allocated where the inputs (e.g., fertilizer), even when produced in a different county, are used.

The complete description of the CO_2 emissions measurement system for the second dataset is offered in Nelson et al. (2009). The authors include on-farm emissions (e.g., use of machinery during field operations) and off-farm emissions (e.g., use of electricity, energy and emissions associated with the production and hauling of fertilizer and pesticide). The ratio output to input that can be built as a result of the datasets above measures total crop production per CO_2 level of input. The greater it is for a county, the more biomass produced per fossil fuel input.

While all these data are not available for all counties on a continuous basis over the whole period (1990–2008), the input and output datasets are compatible with each other because they cover the same counties of the conterminous United States and are expressed in the same units (mega grams of carbon per year). The lack of continuous data forbids us to implement a spatio-temporal statistical approach as brought to the fore in several recent contributions (e.g. Porat et al., 2012; Rey et al., 2012; Ye and Carroll, 2011). However, we still investigate temporal changes in the distribution of crop productivity by calculating the average over 1990–1992 (the initial period) and 2005–2007 (the final period). Averages are preferred over a single year to reduce the effect of changing climate conditions on crop production variance (Ezcurra et al., 2008) and to measure crop production of perennials such as hay (Nelson et al., 2009).

Table 1 shows the descriptive statistics of all variables in 1990–1992 and 2005–2007.

We note that the mean values of carbon output and input per area (cropland area, in unit of acre) have increased, as well as the one of the output-input ratio. On average, output per area increased more (15%) than input per area (12%) during the study periods. As a result, crop productivity measured by the output per input ratio increased by 7% on average. The distribution of output per area in level and growth is much less homogeneous than the one of input per area, as reflected by their respective standard deviations. The ratio of the latter two variables displays even larger standard deviations. These phenomena as well as uncovering which regions display the largest changes in crop productivity will be explored further in the next section.