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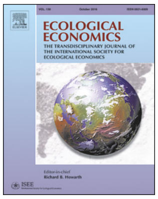

Climate Change and Agriculture: Do Environmental Preservation and Ecosystem Services Matter?

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ABSTRACT

Climate change is expected to cause several impacts on agriculture. Nonetheless, adaptive strategies and environmental sustainability may affect the ability to cope with these impacts. We analyze how agricultural technologies and the ecosystem diversity represented by the land cover have attenuated the impacts of extreme climate events on agricultural production in the São Paulo state, Brazil. Analyses are based on a panel with information for 568 municipalities between 1990 and 2014. We first use multivariate statistical analysis to define six groups of localities according to their levels of agricultural development and land cover. Secondly, based on fixed effect estimates, we analyze the relationship between the dynamics of extreme climate events and agricultural production in each group of localities. Results highlight that both technological and environmental factors could contribute to increases in agricultural production. More importantly, agriculture practiced with high levels of environmental preservation tends to be more resilient to extreme temperature and precipitation events.

1. Introduction

Climate change is expected to cause several impacts on agriculture, primarily through increases in average temperature and in the intensity and frequency of extreme events, such as heavy precipitation and prolonged droughts (IPCC, 2014). Studies have highlighted how less developed regions and more vulnerable farmers tend to be specially affected by climate change, since they lack the basic social and economic capital needed for adaptive strategies, such as access to irrigation and drought-tolerant crops (Mendelsohn and Dinar, 2009; Villamayor-Tomas, 2014; Wreford et al., 2010). South American countries are already suffering the impacts of changes in average rainfall and temperature, increases in the occurrence of warmer nights in tropical regions, and dry spells in semiarid regions (Vergara, 2009; PBMC, 2014; Marengo et al., 2010; Maia et al., 2016).

The patterns of land use and the provision of ecosystem services are also expected to affect the ability to cope with climate change (von Möllendorff and Hirschfeld, 2016). Although humans have appropriated an increasing share of the planet's resources, changes in land use and land cover have potentially undermined the capacity of ecosystems to sustain food production, maintain freshwater and forest resources, regulate climate and air quality, and ameliorate infectious diseases (Foley et al., 2005). The stage in land transition usually encompasses the clearing of natural ecosystems, practices of livestock and agriculture, and finally the expansion of urban areas. Some important consequences of anthropic changes in land use and land cover in South America, mainly through deforestation, extensive livestock and unsustainable agricultural practices, have been hydric degradation, loss of soil fertility, erosion, and desertification (Marengo et al., 2012; The World Bank, 2012).

Changes in the land use and land cover, mainly deforestation and urbanization, have represented one of the main sources of carbon emissions worldwide (IPCC, 2014; The World Bank, 2012; PBMC, 2014). The global consequences of climate change and rising temperature can change the frequency and the intensity of extreme weather events (Hallegatte et al., 2007). In Brazil, for example, the National Institute for Space Research (INPE) projected an increase in average temperature by 2100 from 4 °C to 6 °C in pessimistic scenario, or from 1 °C to 3 °C in optimistic scenario (Marengo, 2007; PBMC, 2014).

The climate change can affect negatively the ecosystem services flow, i.e. the benefits society appropriate from the ecosystem (La Notte et al., 2017), especially through extreme precipitation events (Hallegatte et al., 2007; Millenium Ecosystem Assessment, 2010). Severe droughts contribute to elevate the plant temperature, a regulating

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ecosystem service, due to the closure of the stomata and the reduction of transpiration, and to the increase of pests and diseases due to the reduction of the population size of natural enemies (Rosenzweig et al., 2001). Prolonged droughts also increase the risk of soil erosion by winds, a supporting ecosystem service, and, when followed by heavy rains, increase the potential for flooding due to reduced soil water absorption capacity, which creates favorable conditions for fungal infestation in leaves and roots (Knapp et al., 2008). Extreme events can also affect severely the agricultural production, due to both direct and indirect effects of changes in soil moisture conditions (Rosenzweig et al., 2001), by delaying planting and harvesting operations (van der Velde et al., 2012), leaching and erosion in the absence of conservation-oriented soil management (Deelstra et al., 2011; Jørgensen and Termansen, 2016).

Several studies have analyzed the impacts of climate change on agricultural production (Mendelsohn et al., 1994; Mendelsohn and Dinar, 2009; Dai et al., 2015). More recently, studies have also analyzed how the impacts of climate changes may differ depending on the adoption of adaptive strategies (Schlenker et al., 2003). Adaptive strategies can comprise both agronomic adaptations - e.g. changes in crop varieties and species, timing of operations, and land management, including irrigation - and economic adaptations - e.g. investment in new technologies, infrastructure, and labor (Easterling, 1996). Although the effectiveness varies largely across regions and crops, studies suggest that both agronomic and economic strategies can partially or completely offset the losses of productivity caused by climate change (Burney et al., 2014; Maia et al., 2016; Reidsma et al., 2009). These studies tend to include climate variables in a traditional production function, supposing that input and environmental resources as substitute. Adaptive strategies are important components to attenuate the impacts of climate change, but it also depends on the provision of ecosystem services. Intensive agriculture may potentially undermine the capacity of ecosystem to sustain food production in long term (Foley et al., 2005).

While the use of land have provided useful resources for human activities, allowing them to grow crops, raise animals, obtain timber, and build cities – urbanization –, it has altered a range of essentials ecosystem services, such as providing freshwater, regulation of climate and maintenance of soil fertility (Defries et al., 2004). For example, soil water storage capacity is one of the factors that determine how ecosystems will respond to future changes in precipitation regimes. Soil water storage depends on soil and subsurface soil conditions, as well as vegetation characteristics, such as type, density, species composition and root characteristics (Várallyay, 2010). In urban areas, the soil water storage capacity has been almost lost due to impermeabilization. But in forestry areas, the soil water storage capacity can be maxima. Ecosystems, where there is a predominance of deep roots, may present greater resilience to water fluctuations in the soil (Antonija Kustura et al., 2008; Knapp et al., 2008; Nepstad et al., 1994).

The stage of land use transition, from natural forest to urban areas, is also directly related to the biological diversity. The role of biological diversity in the stability of ecosystems due to environmental fluctuations has been an object of intense debate in the ecological research (Hassan et al., 2005). One of the most important themes linked to this debate is "insurance hypothesis" (Mariotte et al., 2013; Naeem and Li, 1997; Yachi and Loreau, 1999). According to this hypothesis, the diversity of species in an ecosystem increases the chance that ecosystem functions will remain stable in the face of an environmental disturbance or extreme climatic event (Mariotte et al., 2015). An ecosystem with greater diversity would be more likely to have species capable of replacing those less adapted to the new environmental conditions and thus guarantee the stability of a given ecosystem service (Borrvall and Ebenman, 2008).

In this context, we analyze how agricultural technologies and environmental preservation practices may attenuate the impacts of extreme climate events on agricultural production in the state of São Paulo, Brazil. Specifically, we analyze how the impacts of extreme events of precipitation and temperature on the agricultural production may differ according to the levels of land cover, proxy for ecosystem diversity, and the adoption of agronomic and economic strategies. Our main hypothesis is that the use agricultural technologies is necessary, but not sufficient, to create climate resilience in the agricultural production. Ecosystem services would play a central role determining the capability of production techniques to mitigate the impacts of extreme climatic events.

São Paulo is the most developed state in Brazil (IBGE, 2018). In 2015, the São Paulo possessed the highest gross value added of agricultural production among Brazilian states (IBGE, 2018), and the state is the leading national producer of sugarcane/ethanol, sugarcane/sugar and orange juice in Brazil (CEPEA, 2017). The cultivation of the main agricultural product in the São Paulo, sugarcane, is based on rainfed irrigation, making it more dependent on environmental and climate conditions, especially rain patterns. Even though São Paulo state is in a region with high levels of precipitation and a rich supply of fresh water, it has experienced critical moments of water shortage in recent years because of both growth in demand and the reduction in regular supply of water resources. Climate change has been pointed as a main factor responsible for the extremely low levels of precipitation observed in the early 2010s (INMET, 2017). Nevertheless, the historical land use in this highly dynamic region has strongly affected the landscape structure and the provision of ecosystem services related to biodiversity, water, and nutrient cycling (Taniwaki et al., 2017; Ferraz et al., 2014).

2. Data and Methods

2.1. Data Source

Analyses are based on municipal-level data provided by: (i) the Brazilian Institute of Geography and Statistics (IBGE), for data related to agricultural production; (ii) the Institute of Agricultural Economics (IEA), for data related to agronomic and economic strategies; (iii) the National Meteorological Institute (INMET), for data related to climate variables; and (iv) the INPE, for data related to land cover. We aggregated the information of the São Paulo state into 568 MCAs (Minimum Comparable Areas), which are groups of historically comparable municipalities.

São Paulo state is in the Southeastern Brazil (Map 1). This is the most populous (41 million inhabitants in 2010, or 21.6% of national population) and richest state in Brazil (US$ 789,747 million of GDP in 2014, or 32.2% of the Brazilian GDP) (IBGE, 2018). Although the Gross Value Added of the agricultural production represents only 1.7% of the total in the state (US$ 11,617 million in 2014), the agricultural sector plays an important role in the state and in Brazil, because it is well integrated to the industrial and services sectors, the agribusiness (CEPEA, 2017).

2.2. Groups of Land Cover and Production Technologies

The levels of land cover and the adoption of agronomic/economic strategies were defined using multivariate statistical analysis (Morrison, 1990). Cluster analysis was applied to identify three groups of land use/cover. Factor analysis was applied to identify two groups of agronomic/economic strategies. We then joined these two classifications to define 6 groups of *land cover and agronomic/economic technologies*. The flow chart in Fig. 1 summarizes how the groups were defined. The subsections bellow explains more carefully each step.

Based on a panel with 568 MCAs between 1990 and 2014, we then use fixed effect estimates to analyze the relationship between the dynamics of climatic variables and agricultural production in each group of land cover and agronomic/economic technology. We analyze the impacts on the (i) total value of production and (ii) the log of the physical production of sugarcane and orange, the main agricultural

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