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Climate change and farm-level adaptation: the Brazilian *Sertão*

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Abstract

Purpose – The *Sertão*, located in the Northeastern region of Brazil, is the most populous semi-arid region in the world. The region also faces the highest rates of poverty, food insecurity and climate risks in this country. Basic economic activities, such as extensive livestock and dairy farming, tend to be mainly affected by the increasing temperatures and recurrent droughts taking place in the past decades. This paper aims to analyze farmers' responses to climatic variability in the *Sertão*.

Design/methodology/approach – Analyses are based on farm-level data of the Agricultural Census 2006 and on historical climate data gathered by meteorological stations. The climate impacts and the effectiveness of adaptive strategies are compared between three groups of farms, which discriminate different levels of social and environmental vulnerability. Four production functions are modeled (milk, cattle, goat and sheep) accounting for sample selectivity bias.

Findings – In response to increasing temperatures, farmers tend to shift their activities mainly to cattle and dairy farming. But the overall productivity tends to reduce with the recurrence of droughts. Decreasing precipitation affects mainly the production of milk of smallholder family farmers and the cattle herd of non-family farmers.

Research limitations/implications – Analyses do not account for short- and medium-run productive impacts of extreme droughts, which usually have devastating socioeconomic effects in the region.

Originality/value – Smallholder family farmers are the most vulnerable group who deserve more social and technical intervention, as they lack basic social and technological resources that can greatly improve their productivities and overcome the impacts of decreasing precipitation.

Keywords Rural development, Production function, Environmental policy, Rural poverty

Paper type Research paper

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1. Introduction

The Brazilian *Sertão* is the most populous semi-arid region in the world: more than 22 million people in 2010. Despite recent improvements, the region still preserves the highest rates of poverty and food insecurity in Brazil. Expected climate changes may accentuate existing vulnerabilities, as basic economic activities in the region, such as extensive dairy farming and subsistence agriculture, tend to be mainly affected by increasing temperatures and prolonged droughts (Intergovernmental Panel on Climate Change, 2014). In some areas of the *Sertão*, the average temperature increased by more than 2°C over the past 40 years, while the average precipitation fell between 300 and 450 mm, which corresponds to a reduction of 30 per cent (Burney *et al.*, 2014).

The progressive replacement of the native *caatinga* with grass pasture reduced farmers' resilience to climate change, decreasing the water retention capacity of the soil, microbial biomass and exposing the animals directly to the natural environmental conditions (Wick *et al.*, 2000; Andrade-Montemayor *et al.*, 2011). Studies indicated that climate change may severely reduce milk yield and the Gross Domestic Production in the region by nearly 14 per cent (Domingues *et al.*, 2011; Krol *et al.*, 2001; Silva *et al.*, 2002; Silva *et al.*, 2010). A serious limitation of such estimates is that they are based on experimental designs and do not account for a full range of compensatory strategies that may take place in the impacted regions. For example, in response to climate change, farmers may decide to maximize their profit investing in new technologies or shifting their crops and/or livestock (Mendelsohn *et al.*, 1994; Deschenes and Greenstone, 2007). A full range of public policies and/or private initiatives may also attenuate the impacts of climate change, providing agricultural credits, technical assistance, training human resources and strengthening social relations, especially in the most vulnerable rural locations (Simoes *et al.*, 2010; Cesano *et al.*, 2011).

The impacts of climate change may also differ considerably between regions and socioeconomic groups. It is well recognized that the less developed regions and the more vulnerable farmers will be specially affected, as they lack the basic social and economic capital that is needed for adaptive strategies (Maharjan and Joshi, 2013; Wreford *et al.*, 2010; Mendelsohn and Dinar, 2009; Bouroncle *et al.*, 2016). Within developing countries, this asymmetry of conditions and vulnerabilities can particularly be represented by the dichotomies between small/large and family/non-family farms (Zhang *et al.*, 2016). In the *Sertão*, there are roughly 1.5 million family farms, which represent 89 per cent of the total number of farms, but they only accrue 43 per cent of the total area and their average production value is almost six times lower than that of non-family farms (Instituto Brasileiro de Geografia e Estatística, 2006). Their access to basic technologies such as irrigation and technical assistance to overcome recurrent and prolonged droughts is also scarce, making them a vulnerable hotspot for climate change (Jones and Thornton, 2003; Lobell *et al.*, 2008).

This paper analyzed farmers' responses to climate change in the *Sertão*. First, it analyzed the dynamics of climate variables in the last four decades, highlighting trends in average temperatures, precipitation and regional variabilities. Second, based on farm-level data of the Brazilian Agricultural Census 2006, the paper identified the most vulnerable hotspots for climate change in the *Sertão* and how adaptive strategies may attenuate the impacts on different groups of farmers. Four main productions are analyzed: milk, cattle, goat and sheep. By estimating independent production-functions for each economic activity, analyses allow for the farmers' full adjustment to changing environmental conditions in the long run. Moreover, by comparing the impacts of adaptive strategies on different groups of family and non-family farms, the paper evaluates how initiatives that have been largely implemented in this region may have benefited the most vulnerable social groups. Thus, the ultimate objective of this study is to discuss the effectiveness of strategies for vulnerable farmers which would create climate resilience and attenuate the negative impacts of climate change on the small farm agricultural production.

2. Historical background

Climate change is expected to cause several environmental impacts on the semi-arid regions, including increases in water scarcity, average temperature and in the frequency of extreme events, such as prolonged droughts (Intergovernmental Panel on Climate Change, 2014; Kahil *et al.*, 2015). There is also the risk of desertification in some areas, as a result of reduced natural vegetation and an increasing degree of soil aridity (Becerril-Pina *et al.*, 2015; Herrera-Pantoja and Hiscock, 2015). Despite such susceptibility to climatic risks, the semi-arid regions are home to roughly 15 per cent of the world population, most of them characterized by low levels of human development (Millennium Ecossystem Assessment, 2005). The Brazilian *Sertão* is a representative example: 7 out of 22 million residents live under the official poverty line, and the per capita income in this region is twice as low as the national average (Instituto Brasileiro de Geografia e Estatística, 2006).

The combination of vulnerable socioeconomic conditions and climatic risks identifies the so called "vulnerability hotspots" for climate change (Fraser, 2007; Simelton *et al.*, 2009). Small reductions in the average precipitation in these areas can harmfully affect farmers who are already living below poverty line. The economic activity prevailing in semi-arid regions is the extensive livestock, which also directly exposes the animals to natural environmental conditions and, consequently, to the impacts of climate changes (Andrade-Montemayor *et al.*, 2011). The climatic instability can severely limit livestock productivity in these regions, through, for example, water scarcity, reduction in the provision and quality of pastures and forages and increasing number of animal deaths associated with prolonged droughts and severe conditions of heat stress (Megersa *et al.*, 2014; Lioubimtseva and Henebry, 2009). As a result, climate change may also affect farmers' choices for different types of agricultural activity. Kabubo-Mariara (2008), for example, suggests that increasing average temperatures and reducing precipitations tend to make farmers more likely to shift from dairy to beef cattle, and from goat to sheep farming.

The change toward herds that are naturally more resistant to the extreme climate conditions of the semi-arid regions may be a growing trend with climate change. Larger animals face more difficulties in eliminating excess heat, which would reduce their food intake and make them more susceptible to suffer from heat stress (Wreford *et al.*, 2010; Maharjan and Joshi, 2013; Mendelsohn and Dinar, 2009). Larger animals are also more vulnerable to water and food scarcity when compared to smaller animals like goats and sheep. The average daily feed consumption of a cow is roughly eight times higher than that of a sheep. The adoption of small-scale animals in the Brazilian *Sertão* has also shown itself to be related to higher consumption of animal protein, since these families tend to have more diversified systems of production (Toni and Holanda, 2008).

Several other adaptive strategies can also attenuate the impacts of climate change on the agricultural activities of semi-arid regions. Pinheiro (2012) and Insitituto Nacional do Semi-Árido (2008) highlight the need for structural changes in farms, such as the confinement and shading of the livestock, which are essential to minimize production losses, thus alleviating the negative effects of increases in temperature. According to Wossen *et al.* (2014), combined strategies of credit and irrigation supply have been effective in reducing poverty rates and the risk associated with climate variability in drought years. However, according to Cesano *et al.* (2012), irrigation projects in the *Sertão* has proved to be a viable adaptative measure only where perennial water sources are available, and not in the case of small and medium water reservoirs that dry up regularly or at each prolonged drought like small water earth dams. Burney *et al.* (2014) also highlight the potential benefits of irrigation and supplemental feeding of animals. Although these two strategies have proved to be cost-effective, they depend crucially on the availability of water and infrastructure on the farms. Thus, public and private programs to subsidize the access to water for small farmers are essential, either through extracting groundwater or the construction of dams or tanks.

In fact, irrigation has been highlighted as the main adaptive response to mitigate the impacts of decrease in precipitation on crop production (Marshall *et al.*, 2015; Yang and Shumway, 2016; Deschenes and Greenstone, 2007). However, ground water is not a completely renewable resource and the rate of withdrawals surpasses the rate of recharge from precipitation in many situations (so-called "ground water mining"). In the *Sertão*, the areas suitable for irrigation are rare and increasing water scarcity - driven by increased competition for available water supplies and climate-induced shifts in hydrologic systems – potentially tends to constrain irrigation expansion. Moreover, the region does not provide wells with high yields, being mostly smaller subsurface reservoirs and aquicludes, and, most importantly, groundwaters generally have high levels of salinity (Suassuna and Audry, 1995). The construction of earth dams, weirs and cisterns have been stimulated by public agencies, but they tend to be mainly used for animal and human consumption. The public and private costs to implement and maintain larger individual water infrastructures for poor and small farmers would be unsustainable.

Successful adaption strategies will also depend largely on the farmers' perception of climate change (Banerjee, 2014), enhancing the role of information systems that are better aligned with the regional adaptation plans. Some local initiatives have already been implemented in the *Sertão* (see, for example, Simoes *et al.*, 2010), which have shown potential to reduce poverty and improve agricultural production. Nonetheless, their adoptions still rely largely on the efficient actions of a few public authorities and reputable external entities. Local cooperatives and farmers' associations, which tend to have a better knowledge of the local realities and needs, could contribute to disseminate knowledge and technologies, but these initiatives are still very rare in the *Sertão* (Cesano *et al.*, 2011).

3. Data sources and summary statistics

3.1 Climate data

Historical climatic data were obtained from conventional weather stations of the National Meteorological Institute (INMET). Variables comprise daily data of maximum temperature, minimum temperature, average temperature and total precipitation between the years 1974 and 2014. Daily data were interpolated through the 844 historically comparable municipalities located in the semi-arid region. The interpolation was performed by the method of Inverse Distance Weighting (IDW), using the package *gstat* of geostatistical analysis developed by Pebesma (2004) for the statistical program R.

The IDW method is based on the weighted linear combination of the data collected in each meteorological station, using the inverse of the distance as weighting factor. Suppose a sample of n observed spatial points for the climatic variable z. A general equation for an interpolated value z at a given spatial point s using the IDW is:

$$z(s) = \frac{\sum_{i=1}^{N} w_i(s) z_i}{\sum_{i=1}^{N} w_i(s)} \tag{1}$$

where

$$w_i(s) = \|s_i - s\|^{-p} \quad (2)$$

w_i is the IDW function for the spatial point s, s_i is a sampled spatial point and z_i is the data value at the spatial point s_i. The symbol $\|\|$ denotes the Euclidean distance and p is a positive real number, known as power parameter.

As weights are proportional to the inverse of the distances, the larger the distance, the lower the weight. Additionally, the greater the values of p, the greater the weights for values closest to the interpolated point. This study used p equal to 2, as suggested by previous studies using climatic variables (Kurtzman and Kadmon, 1999). Although the interpolation considered the whole sample of 261 weather stations in Brazil, the interpolated values were strongly influenced by those 58 stations located in the *Sertão*. After interpolation, the average daily values of climate variables were aggregated into average and total annual values and estimated separately for each of the municipalities in the region.

The description, average and total values of the climate variables used in the analyses are presented in Table I. Overall, results highlight the high levels of average temperatures and the low levels of rainfall, measured by both the annual precipitation and the number of days per year without rain. The average annual temperature varied between 24 °C in 1974 and 25.4 °C in 2014, while the annual precipitation fell from 129.8 to 79.3 cm.

3.2 Characteristics of farms

The characteristics of family and non-family farmers are analyzed using farm-level data of the Agricultural Census 2006, provided by the *Instituto Brasileiro de Geografia e Estatística* (IBGE). The information refers to 961,544 farms in the *Sertão* in 2006 with agricultural land higher than zero. Farms were initially divided into two main groups: family and non-family. Family farms were classified according to the Federal Law 11326 of 07/24/2006, which is officially used for targeted policies in Brazil. According to this law, family farmers are those who fall into all of these categories:

- the total area owned is lower than a regional threshold level;
- the labor force is predominantly from the family;
- the family income is predominantly from their own farm; and,
- the farm is managed by the family (Guanziroli *et al.*, 2012).

According to these sets of criteria, there were 855,930 family farms (89 per cent of the total) and 105,614 non-family farms (11 per cent of the total) in the *Sertão* in 2006.

Table I. Climate variables for the municipalities in the Sertão, 1974-2014

Variable	Description	1974	2014
Climate			
Maxtemp	Annual average of the maximum daily temperatures (°C)	29.6	30.4
Avgtemp	Annual average of the mean daily temperatures (°C)	24.0	25.4
Mintemp	Annual average of the minimum daily temperatures (°C)	19.6	20.4
Precip	Total annual rainfall (cm)	129.8	79.3
Norain	Number of days in the year with rainfall lower than 1 mm (days)	232	271

Source: INMET

To account for the heterogeneity within this wide group of family farms, a second criterion discriminated the most vulnerable ones. The family farms were then divided into two additional groups: family farms D, those with farm income lower than a regional threshold; family farms ABC, those with farm income higher than this regional threshold. The regional threshold was defined by the FAO (Food and Agriculture Organization), based on an opportunity cost of the labor in each region, a proxy for the regional level of subsistence (Guanziroli *et al.*, 2012). According to this criterion, there were 368,795 family farms ABC in the *Sertão* and 487,135 family farms D.

Analyses considered a wide range of characteristics of the farms, such as area and labor force; characteristics of the farmers, such as education and membership of a cooperative; and characteristics of the production systems, such as the use of technologies, soil treatment and technical guidance. The list of variables used in these analyses is presented in Table II, and they refer to the 2005-2006 harvest.

Four types of production variables were considered: liters of milk, head of cattle, goats and sheep. On an average, non-family farms are six times larger than family farms ABC and ten times larger than family farms D (114 versus 11 and 20 hectares, respectively) and their herds are between two (sheep) and 12 (cattle) times higher. The beef cattle prevailed among both types of farms, practiced with a very low level of intensification. The average number of heads per farm is lower than 8.5 for family farming and equal to 40 for non-family farming, which correspond to 1.0 and 0.7 heads per hectare of pasture (the sum of natural, degraded and non-degraded pastures), respectively. Sheep and goat herds are also traditional in the region. The average number of heads of sheep is 2.3 for family farm D, 5.2 for ABC and 11.8 for non-family farm. In addition, there were, on average, 1.8 heads of sheep per family farm D, 3.5 per family farm ABC and 9.0 per non-family farm. The average milk yield is substantially higher among non-family farms: 3,975 liters per year, which amounts to an average yield of 1,033 liters per cow. This milk yield is 53 per cent higher than that of family farms D (677 liters/cow) and 12 per cent higher than that of family farms ABC (926 liters/cow).

Five types of land use are considered: natural pasture area (*anatpast*), degraded pasture area (*adegpast*), non-degraded pasture area (*andegpast*) planted area of forage (*aforage*) and area of forest (*aforest*). They are proxies for inputs and capital in the livestock production and can also be used to control environmental resources, such as pasture quality and shade for cattle. Natural pastures are areas of brush grass, *caatinga*, savanna, among others, used for grazing. Planted pastures are divided into:

- degraded pasture, not very productive areas which are degraded by inadequate management or lack of conservation; and
- non-degraded, in good condition and more productive areas (including those in the process of recovery).

Natural pasture areas prevail in the farms (roughly one-third of the total area). The three types of pasture areas (*anatpast*, *adegpast* and *andegpast*) represent more than half of the farm size. The share of non-degraded areas is slightly higher among non-family farms: 19 against 18 per cent of family farms ABC and D. Areas of forage, which is usually palm, adds less than 4 per cent of the total area in family and non-family farms.

The labor force is controlled by the variable *lf*, which corresponds to the sum of family labor (including the own farmers) and hired labor. The average number of workers is roughly the same between family and non-family farms, ranging between 2.4 and 2.6. The share of members of cooperatives (*coop*), a proxy for social capital, is very low in the *Sertão*,

Variable	Description	Family D	Family ABC	Non-family
Farms		487,135	368,795	105,614
Production				
Milk	Dairy production (liters)	250	1,514	3,975
Cattle	Cattle production (heads)	3.5	8.5	39.9
Goat	Goat production (heads)	1.8	3.5	9.0
Sheep	Sheep production (heads)	2.3	5.2	11.8
Area and inputs				
Atotal	Total area (ha)	11.06	20.13	114.36
Anatpast	Natural pasture area (ha)	2.80	5.10	31.65
Adegpast	Degraded pasture area (ha)	0.39	0.65	3.63
Andegpast	Not degraded pasture area (ha)	1.48	2.73	18.91
Aforage	Forage area (ha)	0.33	0.57	3.14
Aforest	Forest area (ha)	3.31	6.40	40.73
Cow	Number of cows (heads)	0.37	1.64	3.84
lf	Total labor force (persons)	2.34	2.51	2.56
Farmer's characteristics				
Female	1 if the farmer is a woman (0,1)	0.166	0.171	0.085
Age	Farmer's age (years)	46.740	56.776	47.403
School00	1 if the farmer is illiterate (reference of analysis)	0.395	0.486	0.289
School10	1 if the farmer has elementary education with no diploma (0,1)	0.507	0.443	0.486
School11	1 if the farmer has elementary education with diploma (0,1)	0.052	0.036	0.075
School23	1 if the farmer has secondary or superior education (0,1)	0.046	0.035	0.149
Technology and orientation				
Coop	1 if member of cooperativism (0,1)	0.013	0.020	0.045
Atraction	1 if farm used animal traction (0,1)	0.391	0.473	0.474
Mtraction	1 if farm used mechanical traction (0,1)	0.232	0.305	0.375
Guidance	1 if farm received technical assistance (0,1)	0.065	0.098	0.173
Diseasec	1 if the farm realized control of diseases or parasites in animals (0,1)	0.364	0.562	0.597
Land management				
Fertilizep	1 if farm fertilized pasture (0,1)	0.013	0.021	0.048
Integration	1 if farm used crop to recover pasture (0,1)	0.047	0.058	0.073
Rest	1 if farm used fallow or rest to recover pasture (0,1)	0.084	0.123	0.122
Rotation	1 if farm realized pasture rotation (0,1)	0.103	0.196	0.251
Adaptive measures				
Well	1 if farm had a water well (0,1)	0.152	0.244	0.339
Weir	1 if farm had a weir (0,1)	0.095	0.163	0.223
Cistern	1 if farm had a cistern (0,1)	0.242	0.312	0.283
Market and credit				
Specialized	1 if the farm was specialized in one product (0,1)	0.534	0.542	0.594
Integrated	1 if the farm was integrated to the market (0,1)	0.344	0.482	0.559
Credit	1 the farm received credit (0,1)	0.128	0.176	0.126

Source: Agricultural Census 2006 (IBGE)

Table II. Average values for family and non-family farms in the *Sertão*, 2006 but is higher among non-family farms: 4.5 per cent as against 1.3 per cent for family farms D and 2.0 per cent for family farms ABC.

Human capital and social relations were analyzed by variables related to gender (*female*), age (*years old*) and education: no education (reference of analysis); elementary education with no diploma (*school*10); elementary education with diploma (*school*11); and technical, secondary or college education (*school*23). The share of farms operated by women is twice as high among family farms: 17 per cent as against 8.5 per cent of non-family farms. Family farmers ABC are, on average, older and less educated than family farmers D and non-family farmers. The former group is on average 10 years older than the latter and 48.6 per cent of them have no formal education, as opposed to 39.5 per cent of the family farmers D and 29 per cent of the non-family farmers. In other words, groups ABC and D may represent two different generations of the family farms.

Use of technologies was analyzed by the variables *atraction* (if the farm uses animal traction), *mtraction* (if the farm uses mechanical traction) and *diseasec* (if the farm controls diseases or parasites in animals). The variable *guidance* indicates whether the farm received technical assistance by qualified professionals. The use of good agricultural practices considers fertilization of pastures (*fertilizep*), use of lime or other corrective measures of soil ph (*soilcor*), use of fallows or rest to recover pasture (*rest*), use of crops to recover pasture (*integration*) and use of pasture rotation (*rotation*).

Non-family farms present the best results for all variables. Mechanical traction, for example, is used by 37 per cent of non-family farms, 30 per cent of family farms ABC and 23 per cent of family farms D. The use of animal traction is still high, for all groups of farms (ranging between 39 per cent – D – and 47 per cent – ABC and non-family farms). The control of diseases or parasites in animals is practiced by almost 60 per cent of non-family farms and family farms ABC, as opposed to only 36 per cent of family farms D. In turn, technics of soil treatment or fertilization of pastures are rare: no more than 2 per cent among family farms and 5 per cent among non-family farms. Rotation is the preferred technique to preserve pastures, and it is practiced by 25 per cent of non-family farms, as against 20 per cent of family farms ABC and only 10 per cent of family farms D. The percentage of farms that received some technical guidance is remarkably low, ranging between 6 per cent (family farms D) and 17 per cent (non-family farms).

The use of adaptive strategies for droughts was analyzed by the existence of cisterns (*cistern*), wells (*well*), natural lake or weir (*weir*); and control of diseases or parasites in animals (*diseasec*). The construction of cisterns has been the main policy to fight droughts in the Brazilian semi-arid region and prevails among the less vulnerable family farms: 31 per cent of family farms ABC had cisterns in 2006, against 24 per cent of family farms D and 28 per cent of non-family farms. Wells are also relatively frequent among non-family farms (34 per cent) and family farms ABC (24 per cent) but are rarer among family farms D (15 per cent). Nonetheless, it must be considered that many wells in the *Sertão* are saline or brackish water and cannot be used (Cesano *et al.*, 2012). According to Suassuna and Audry (1995), most surface and underground waters in the *Sertão* present electrical conductivities between 750 and 15,000 μSiemens/cm and salinity between 5 and 11 ppt.

Two variables defined by FAO (Food and Agriculture Organization) and INCRA (National Institute of Colonization and Agrarian Reform) (Guanziroli, 2001) helped to characterize the production system: the degree of specialization and the degree of market integration. The degree of specialization, which is measured by the ratio between the production value of the main product and the total production value, was analyzed by dummy variable *specialized*, which assumes 1 when the degree of specialization is greater than 0.65. The share of specialized farms is slightly lower among family farms: 53 per cent for group D and 54 per cent for group ABC, as against 59 per cent for non-family farms.

In turn, the degree of market integration, which is measured by the ratio between the total revenue from agricultural activity and the total value of agricultural production, was analyzed by the dummy variable *integrated*, which assumes 1 when the degree of integration is higher than 0.5. Almost two-thirds of the family farms D were poorly integrated, i.e. their revenues from agricultural products represented less than 50 per cent of total agricultural production, which reflects the prevalence of self-subsistence agriculture. Among family farms ABC and non-family farms, 52 and 44 per cent were poorly integrated, respectively.

Finally, access to credit was analyzed by the binary variable *credit*, which identifies whether the family farm obtained funding from private or public agencies. PRONAF (National Program to Strengthen Family Farming) is the main public funding program for small family farms in Brazil and concentrate most of the loans granted in the *Sertão*. The percentage of farms receiving credit in 2006 was substantially low, ranging between 13 and 18 per cent. Nonetheless, it must be considered that this value refers only to loans contracted in 2006. As the period of payment is up to 10 years, with up to three-year grace period, the percentage of farms assisted by credit is probably higher.

4. Econometric strategy

4.1 Cross-sectional analysis of farm production

The impacts of the characteristics of farms, adaptive strategies and climate variables on the farm production was based on multiple regression models, using farm-level data of the Agricultural Census 2006. The models assume that the agricultural production is a linear function of a set of explanatory factors (vector **x**). The dependent variable of each model is represented by the natural logarithm of the types of agricultural production (milk, cattle, sheep and goat). The model for each type of production can preliminarily be represented by:

$$\ln Y_i = \mathbf{x}_i^{'}\boldsymbol{\beta} + r_i + \varepsilon_i \tag{3}$$

Where the subscript i refers to the i-th farm and the set of dependent (Y) and independent variables (**x**) is presented in Table II. In addition to the characteristics of the farmers and farms, **x** also contains climatic variables representing the average temperature (*avgtemp*), total precipitation (*precip*) and squared precipitation (*precip*^{2}) in the harvest years 2005-2006. Geographical differences between the regions, such as soil quality and historical background, are represented by the factor r_i and controlled by dummy variables representing 33 official regions in the *Sertão*. The variable ε is the random error, which represents factors that are not controlled in the model. The vector of coefficients β indicates the net impacts of the explanatory factors on ln Y, which means, the percentage impacts of variables in **x** on Y. In the case of a dummy explanatory variable, the percentage impact is given by the expression $e^{\beta} - 1$ (Halvorsen and Palmquist, 1980).

The problem in equation (1) is that the production Y_i is only observed for a subset population of farmers with positive values of production ($Y_i > 0$). Because information with null values of production ($Y_i = 0$) is not used to estimate equation (1), estimates tend to be subjected to a problem known as *sample selection bias* (Wooldridge, 2003).

The data used in this study refer to a nonrandom sample selection of farmers, and their decision to produce, that is, the probability of $Y > 0$, will depend on the outcome of several variables. Among these variables, there are observed factors that can be controlled by **x**, such as characteristics of the farmer and farm, geographical location and previous climate experiences. But this nonrandom sample selection is also affected by unobserved factors, such as entrepreneurship and socioeconomic capital. The problem is that the ordinary least squares' estimators will be inconsistent if these unobserved factors are also related to production Y (Wooldridge, 2003, p. 506).

The usual approach to represent this type of sample selection is to add a new selection model to equation (1):

$$W_i^* = \mathbf{z}'_i \boldsymbol{\varphi} + r_i + \omega_i, \qquad W_i = \begin{cases} 1 \text{ if} & W_i^* > 0 \\ 0 \text{ if} & W_i^* \leq 0 \end{cases} \tag{4}$$

$$\ln Y_i = \mathbf{x}_i' \boldsymbol{\beta} + r_i + \varepsilon_i, \text{ if } \mathrm{W}_i = 1 \tag{5}$$

Where ω_i and ε_i are jointly normal with zero mean, standard deviations of 1 and σ, and correlation of ρ. Vectors $\mathbf{z}$ and $\mathbf{x}$ contain, respectively, the determinants of the production choices ($Y > 0$) and the total production (Y). The method of maximum likelihood is used to estimate the coefficients in vectors φ and β. All the variables presented in $\mathbf{x}$ are also included in $\mathbf{z}$.

The consistency of the estimates of the selection models relies on the existence of good instrumental variables in vector $\mathbf{z}$ (Wooldridge, 2003, p. 564). In other words, vector $\mathbf{z}$ needs to include variables that are properly related to the decision to produce equation (3) but not related to the total production [equation (4)]. These instrumental variables can be adequately represented by the farmers' previous climate experiences: average temperature between 1974 and 2004 (*p_avgtemp*), average annual precipitation between 1974-2004 (*p_precip*) and squared average annual precipitation between 1974-2004 (p_precip^2). This means that the climate experiences in the past 30 decades are assumed to affect the choices for different types of production ($Y > 0$). But the current agricultural production (Y) will only be affected by the climate experiences in the crop 2005-2006.

5. Results

5.1 Climate variability

Figure 1 illustrates the historical values of the climate variables and highlights clear trends of increasing temperature and decreasing precipitation in the *Sertão*. For example, the mean value of average temperatures in the 1970s was 24.2°C and it

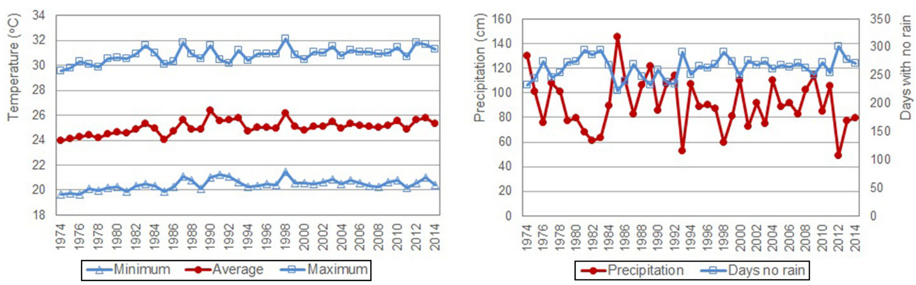
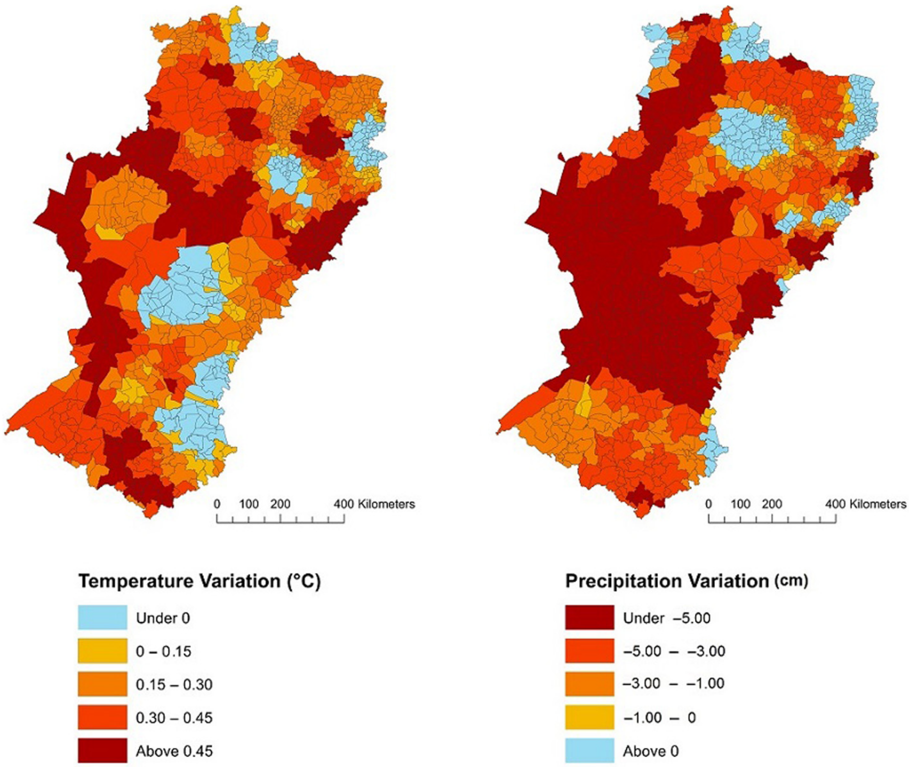


Figure 1. Temperature (minimum, average and maximum annual temperatures) and precipitation (annual total precipitation and days with no rain) in the Sertão, 1974-2014

Source: Elaborated using data from INMET increased to 25.4°C in the 2010s. In the same period, the mean value of minimum temperatures increased from 19.9 °C to 20.6°C, and of maximum temperatures increased from 30.0°C to 31.4°C.

At the same time, the *Sertão* has witnessed increasing number of days without rain and decreasing precipitation. For example, the annual precipitation decreased from 988 cm in the 1970s to 791 cm in the 2010s. The average number of days without rain in the year increased from 254 to 275. Periods of extreme and extended droughts were observed in the first half of the 1980s, 1990s and 2010s.

Climate change in the *Sertão* varies in time and space. Figure 2 illustrates the spatial distribution of the average temperature and precipitation variation per decade in each municipality, highlighting how changes are not homogeneous in the region[1]. Changes were more extreme in the midwestern part of the *Sertão*, where precipitation reduced by more than 5 cm per decade and average temperature increased by more than 0.45°C per decade in several municipalities. By contrast, few areas, mainly in the northeastern and mideastern parts of the *Sertão*, presented positive variation in precipitation and negative variation in temperature.



Source: Elaborated using data from INMET

Figure 2. Average variation per decade in temperature and precipitation

5.2 The net impact of characteristics of the farms on production

Tables III and IV present the maximum likelihood estimates for the production function equations accounting for sample selection bias equation (4). Models were adjusted separately for each group of farms and for each production type: total liters of *milk*; *cattle* herd; *sheep* herd; and *goat*. Most estimates are significant at 0.01 per cent level. There are no striking differences between the estimates for family and non-family farms, i.e. they seem to be equally benefited by the measures under analysis. The selection bias shows itself to be a relevant problem in the estimation of the production functions, as the correlation estimates (ρ) are significant in all equations. The number of observations and the statistic of goodness of fit (log likelihood) for each model are also presented in the bottom lines of the tables.

5.2.1 Areas and inputs. As expected, the different types of areas of pasture, proxies of physical capital, tend to have significant positive net impacts on the livestock, with no substantial difference between family and non-family farms. The net impacts of natural pastures and areas with non-degraded grazing are larger, especially for cattle production (output elasticities ranging between 0.09 and 0.15 per cent). Goats and sheep are less influenced by the grazing areas (elasticities ranging between 0.02 and 0.10 per cent), as they are easy in adapting to different environmental conditions.

Milk production seems to be practiced using more intensive techniques, as the net impact of areas of pasture on milk yield is low or even negative. In reality, both livestock and milk yield depend significantly on forage areas (*aforage*). This is one of the main adaptive strategies stimulated by the local agencies in the region. The areas of forest (*aforest*) may also provide food for the herd in periods of droughts, but the overall impact is limited (elasticities ranging between 0.03 per cent for goat and 0.07 per cent for cattle). The integration between areas of pasture and forest (*anatpast*) is more disseminated in the territory and produces more relevant impacts on the herd (elasticities ranging between 0.03 per cent for sheep and 0.10 per cent for cattle).

The labor force is controlled by the total number of employees in the agricultural activity (*lf*), but this variable presents small or no positive impact on production, as other factors are controlled. This means, the livestock production in the region is a non-labor-intensive activity.

5.2.2 Farmers' characteristics. Probably reflecting a gender division of labor in the *Sertão*, farms run by women present a lower livestock than men's. For example, the cattle herd is 18.5 per cent lower ($e^{-0.205} - 1$) for family farms D and 22.4 per cent lower ($e^{-0.253} - 1$) for family farms ABC. Only the milk production presents similar values between family farms headed by women or men.

Livestock tends to be greater for those farms headed by older people. The number of cattle head on family farms D increases by 1.1 per cent for each additional year of farmer's age. The selection and accumulation of species resistant to such extreme conditions requires investments and knowledge that may not be easily accessible for younger farmers.

Educational attainment, another proxy for human capital, is also positively related to the agriculture production. The net returns are greater for livestock, which may also be related to the investments and knowledge that are needed to increase the herd. Farmers that can only read and write (variable *escola*01) present a number of cattle head that is 16.6 per cent ($e^{0.153}-1$) higher than that of farmers with no education among family farms D and 13.6 per cent ($e^{0.128}-1$) higher among non-family farms. The livestock grows more intensively if the farmer has fundamental or more education (variables *escola*11 and *escola*23).

5.2.3 Technology and orientation. Cooperativism, albeit not yet widespread in the region, presents positive and substantial impacts on cattle and milk production. Cooperatives in the *Sertão* play important roles providing technical and financial assistance, as well as

Table III. Maximum likelihood estimates of the sample selection models for the log of milk and cattle, 2006

Regressors	ln(*milk*) Family D	Family ABC	Non-family	ln(*cattle*) Family D	Family ABC	Non-family
Intercept	6.018*** (0.106)	7.448*** (0.078)	8.851*** (0.180)	0.314*** (0.078)	0.553*** (0.068)	0.452** (0.167)
Cow	0.110*** (0.001)	0.083*** (0.001)	0.041*** (0.000)			
ln(*anatpast*)	0.006*** (0.002)	0.002* (0.001)	0.002 (0.002)	0.092*** (0.001)	0.083*** (0.001)	0.099*** (0.002)
ln(*adegpast*)	−0.013*** (0.003)	−0.015*** (0.002)	−0.010** (0.004)	0.098*** (0.002)	0.080*** (0.002)	0.059*** (0.003)
ln(*andegpast*)	−0.013*** (0.002)	−0.002 (0.001)	0.012*** (0.003)	0.146*** (0.001)	0.132*** (0.001)	0.139*** (0.002)
ln(*aforage*)	0.020*** (0.003)	0.043*** (0.002)	0.027*** (0.004)	0.109*** (0.002)	0.095*** (0.002)	0.072*** (0.003)
ln(*aforest*)	−0.007*** (0.001)	−0.017*** (0.001)	−0.007** (0.002)	0.065*** (0.001)	0.059*** (0.001)	0.069*** (0.002)
lf	0.001 (0.002)	0.000 (0.002)	0.030*** (0.004)	0.014*** (0.001)	0.021*** (0.001)	0.081*** (0.003)
female	0.012 (0.010)	0.005 (0.008)	−0.080** (0.022)	−0.205*** (0.007)	−0.253*** (0.006)	−0.300*** (0.018)
Age	−0.002*** (0.000)	−0.003*** (0.000)	−0.001** (0.000)	0.011*** (0.000)	0.005*** (0.000)	0.007*** (0.000)
School10	−0.020** (0.007)	0.006 (0.005)	0.022 (0.014)	0.153*** (0.004)	0.174*** (0.004)	0.128*** (0.011)
School11	0.020 (0.015)	0.105*** (0.013)	0.136*** (0.023)	0.279*** (0.010)	0.338*** (0.010)	0.271*** (0.018)
School23	0.041** (0.016)	0.112*** (0.014)	0.184*** (0.019)	0.390*** (0.011)	0.444*** (0.010)	0.356*** (0.015)
Coop	0.120*** (0.020)	0.138*** (0.014)	0.147*** (0.026)	0.109*** (0.015)	0.126*** (0.011)	0.189*** (0.020)
Atraction	0.028*** (0.006)	−0.014** (0.005)	−0.036** (0.012)	0.026*** (0.005)	0.030*** (0.004)	0.048*** (0.010)
Mtraction	0.086*** (0.007)	0.069*** (0.005)	0.159*** (0.012)	0.060*** (0.005)	0.107*** (0.004)	0.164*** (0.010)
Guidance	0.036** (0.010)	0.067*** (0.007)	0.082*** (0.015)	0.037*** (0.007)	0.030*** (0.006)	0.120*** (0.012)
Fertilizep	0.127*** (0.017)	0.166*** (0.013)	0.187*** (0.023)	0.136*** (0.013)	0.125*** (0.010)	0.079*** (0.018)
Integration	0.023^{+} (0.012)	0.063*** (0.009)	0.076** (0.021)	0.034*** (0.008)	0.029*** (0.007)	−0.007 (0.016)
Rest	0.011 (0.010)	−0.046*** (0.007)	−0.063** (0.017)	−0.072*** (0.007)	−0.095*** (0.005)	−0.180*** (0.014)
Rotation	−0.062*** (0.008)	−0.074*** (0.006)	−0.116*** (0.013)	0.144*** (0.006)	0.076*** (0.005)	0.068*** (0.011)
Diseasec	−0.199*** (0.009)	−0.382*** (0.007)	−0.778*** (0.019)	0.410*** (0.012)	0.273*** (0.009)	0.138*** (0.021)
Well	0.062*** (0.007)	0.058*** (0.005)	0.056*** (0.013)	0.146*** (0.005)	0.144*** (0.004)	0.283*** (0.010)
Weir	0.024** (0.009)	−0.023** (0.006)	0.008 (0.013)	0.122*** (0.006)	0.093*** (0.005)	0.245*** (0.011)
Cistern	−0.007 (0.007)	−0.014** (0.005)	−0.062*** (0.013)	−0.035*** (0.005)	−0.042*** (0.004)	−0.102*** (0.010)
Specialized	0.350*** (0.007)	0.322*** (0.005)	0.469*** (0.013)	0.139*** (0.004)	0.184*** (0.004)	0.493*** (0.010)
Integrated	0.444*** (0.007)	0.450*** (0.005)	0.521*** (0.013)	0.221*** (0.004)	0.323*** (0.004)	0.301*** (0.010)
Credit	0.013^{+} (0.008)	0.008 (0.006)	−0.096*** (0.016)	0.000 (0.005)	−0.055*** (0.005)	−0.213*** (0.013)
Avgtemp	0.018*** (0.002)	−0.002 (0.002)	−0.015** (0.004)	0.012*** (0.002)	0.027*** (0.001)	0.023*** (0.004)
Precip	0.007*** (0.001)	0.008*** (0.001)	0.001 (0.002)	0.008*** (0.001)	0.008*** (0.001)	0.013*** (0.002)
$Precip^2$	−3.E-5*** (0.000)	−4.E-5*** (0.000)	−8.E-6 (0.000)	−4.E-5*** (0.000)	−4.E-5*** (0.000)	−5.E-5*** (0.000)

(*continued*)

Table III.

Regressors	Family D	ln(*milk*) Family ABC	Non-family	Family D	ln(*cattle*) Family ABC	Non-family
Region	yes	yes	yes	yes	yes	yes
σ	0.796***	0.928***	1.210***	0.790***	0.809***	1.039***
ρ	−0.696***	−0.910***	−0.939***	0.292***	0.065***	−0.166***
n	343,689	330,231	84,770	343,689	330,231	84,770
Log likelihood	−133,059	−247,856	−78,544	−343,387	−381,864	−110,807

Notes: Standard errors between parentheses; ***Significant at 0.1%; **Significant at 1%; *Significant at 5%; +Significant at 10%
Source: Devised using microdata of the Agricultural Census 2006

Table IV. Maximum likelihood estimates of the sample selection model for the log of goat and sheep, 2006

Regressors	ln(*goat*) Family D	ln(*goat*) Family ABC	ln(*goat*) Non-family	ln(*sheep*) Family D	ln(*sheep*) Family ABC	ln(*sheep*) Non-family
Intercept	1.442*** (0.200)	3.629*** (0.210)	3.193*** (0.441)	2.299*** (0.165)	3.482*** (0.151)	2.548*** (0.292)
ln(*anatpast*)	0.047*** (0.003)	0.049*** (0.002)	0.057*** (0.005)	0.027*** (0.002)	0.028*** (0.002)	0.042*** (0.003)
ln(*adegpast*)	0.046*** (0.006)	0.037*** (0.005)	0.026** (0.008)	0.043*** (0.004)	0.021*** (0.003)	0.024*** (0.005)
ln(*andegpast*)	0.059*** (0.004)	0.046*** (0.003)	0.057*** (0.005)	0.053*** (0.002)	0.047*** (0.002)	0.059*** (0.003)
ln(*aforage*)	0.018*** (0.004)	0.023*** (0.004)	0.029*** (0.006)	0.021*** (0.003)	0.019*** (0.003)	0.035*** (0.004)
ln(*aforest*)	0.034*** (0.003)	0.029*** (0.002)	0.044*** (0.004)	0.044*** (0.002)	0.035*** (0.002)	0.040*** (0.003)
lf	−0.033*** (0.003)	−0.030*** (0.003)	−0.002(0.007)	−0.026*** (0.002)	−0.016*** (0.002)	0.015** (0.004)
Female	−0.198*** (0.014)	−0.271*** (0.014)	−0.317*** (0.040)	−0.184*** (0.011)	−0.245*** (0.010)	−0.241*** (0.027)
Age	0.011*** (0.000)	0.006*** (0.000)	0.009*** (0.001)	0.010*** (0.000)	0.006*** (0.000)	0.007*** (0.000)
School10	0.173*** (0.010)	0.209*** (0.011)	0.172*** (0.025)	0.153*** (0.008)	0.158*** (0.007)	0.147*** (0.017)
School11	0.283*** (0.023)	0.395*** (0.028)	0.252*** (0.045)	0.307*** (0.018)	0.302*** (0.019)	0.227*** (0.029)
School23	0.382*** (0.026)	0.478*** (0.030)	0.437*** (0.036)	0.355*** (0.019)	0.400*** (0.019)	0.388*** (0.024)
Coop	0.022 (0.039)	0.072* (0.035)	0.007 (0.052)	0.078** (0.029)	0.063** (0.022)	0.040 (0.033)
Atraction	−0.043*** (0.010)	−0.067*** (0.011)	−0.080** (0.023)	−0.114*** (0.008)	−0.119*** (0.007)	−0.090*** (0.015)
Mtraction	0.176*** (0.013)	0.169*** (0.012)	0.095** (0.025)	0.081*** (0.009)	0.080*** (0.007)	0.128*** (0.015)
Guidance	0.048** (0.017)	0.053** (0.016)	0.057* (0.028)	0.067*** (0.013)	0.028** (0.010)	0.079*** (0.018)
Fertilizep	−0.089** (0.033)	−0.046 (0.029)	0.001 (0.044)	0.032 (0.026)	0.048* (0.020)	-0.047^{+} (0.028)
Integration	0.009 (0.022)	-0.039^{+} (0.021)	−0.103* (0.042)	−0.045** (0.015)	−0.032* (0.013)	−0.079** (0.026)
Rest	−0.001 (0.016)	−0.016 (0.015)	-0.063^{+} (0.032)	−0.013 (0.012)	−0.028** (0.010)	−0.049* (0.020)
Rotation	−0.042** (0.016)	−0.043** (0.014)	−0.019 (0.027)	−0.043*** (0.010)	−0.035*** (0.008)	−0.012 (0.016)
Diseasec	−0.083*** (0.013)	−0.067*** (0.014)	−0.051 (0.043)	−0.131*** (0.012)	−0.109*** (0.012)	−0.117** (0.031)
Well	0.038** (0.012)	0.024* (0.011)	0.112*** (0.025)	0.003 (0.009)	0.001 (0.008)	0.089*** (0.017)
Weir	0.087*** (0.015)	0.080*** (0.013)	0.275*** (0.026)	0.063*** (0.011)	0.067*** (0.009)	0.163*** (0.017)
Cistern	−0.120*** (0.011)	−0.086*** (0.011)	−0.098** (0.026)	−0.127*** (0.008)	−0.084*** (0.008)	−0.092*** (0.016)
Specialized	0.191*** (0.012)	0.112*** (0.012)	0.209*** (0.028)	0.099*** (0.009)	0.046*** (0.008)	0.167*** (0.017)
Integrated	0.234*** (0.011)	0.259*** (0.011)	0.340*** (0.023)	0.157*** (0.008)	0.192*** (0.007)	0.269*** (0.016)
Credit	0.018 (0.013)	−0.066*** (0.013)	−0.168*** (0.032)	0.000 (0.009)	−0.034*** (0.009)	−0.139*** (0.020)
Avgtemp	0.036*** (0.004)	0.004 (0.004)	−0.031** (0.009)	0.032*** (0.004)	0.006^{+} (0.003)	0.016* (0.007)
Precip	0.006*** (0.001)	−0.004* (0.002)	0.000 (0.003)	-0.002^{+} (0.001)	−0.010*** (0.001)	−0.005* (0.002)
$Precip^2$	−4.E-5*** (0.000)	−8.E-6 (0.000)	−4.E-5* (0.000)	−2.E-6 (0.000)	2.E-5** (0.000)	7.E-6 (0.000)

(*continued*)

Table IV.

Regressors	Family D	ln(*goat*) Family ABC	Non-family	Family D	ln(*sheep*) Family ABC	Non-family
Region	yes	yes	yes	yes	yes	yes
σ	1.174***	1.253***	1.353***	1.005***	1.035***	1.115***
ρ	−0.709***	−0.696***	−0.579***	−0.664***	−0.660***	−0.555***
n	343,689	330,231	84,770	343,689	330,231	84,770
Log likelihood	−178,801	−184,868	−53,547	−215,380	−246,090	−73,097

Notes: Standard errors between parentheses; ***Significant at 0.1%; **Significant at 1%; *Significant at 5%; +Significant at 10%
Source: Devised using microdata of the Agricultural Census 2006

integration in the consumer market. The average number of cattle head for cooperative farms is 11.6 per cent higher ($e^{0.109}-1$) than that of non-cooperative farms among family farmers D and 13.4 per cent higher ($e^{0.126}-1$) among family farms ABC.

Development of mechanical technologies adapted to semi-arid conditions has been an important ally for soil management, use of rain water, cultivation and preparation of animal feed (Albiero *et al.*, 2015). The use of mechanical traction implies in positive and significant impacts on all types of agricultural production, for family and non-family farms. For example, family farms ABC and D using mechanical traction have, on average, 18.4 and 19.3 per cent ($e^{0.176}-1$ and $e^{0.164}-1$) more goat heads than those with no mechanical traction. In turn, there is no concrete evidence that animal traction can improve the agricultural production in the *Sertão*.

Farms receiving technical guidance tend to be more productive. The positive impacts range between 2.8 per cent (heads of sheep of family farms ABC) and 12.7 per cent (cattle herd of non-family farms). Despite limited achievements – less than 10 per cent of farms in the *Sertão* received technical guidance in 2006 – and the fact that the variable *guidance* does not discriminate accurately the quality and duration of the assistance, these positive impacts largely reflect the efforts of private and public agricultural agencies in disseminating knowledge and good agricultural practices.

Among the production techniques under analysis, the control of diseases and pests in animals is the one with the largest partial effects on cattle farming. Family farmers who perform this type of control have a mean number of cattle head that is between 31.5 per cent ($e^{0.273}-1$, for family farms ABC) and 50.6 per cent ($e^{0.410}-1$, for family farms D) higher than others (14.9 per cent higher among non-family farmers). In turn, the negative effects of *diseasec* on the production of milk, goat and sheep, may probably indicate a specialization in the cattle production once this technique is adopted in the farm. In other words, farmers would prefer to reduce alternative productions to invest exclusively in the most profitable production.

5.2.4 Land management. The net effect of fertilization in pastures is positive and significant on the production of cattle and milk. For example, family farms D that fertilize pastures present a mean milk production that is 13.6 per cent higher ($e^{0.127}-1$) than others.

In turn, methods of soil management present divergent impacts. Pasture rotation tends to affect the size of the cattle herd positively, although it can compromise other types of production, like goat, sheep and milk. In turn, the fallow, resting or strategies to cultivate crops for pasture recovery tend to affect negatively all types of livestock production, as it generates an opportunity cost in the short term. Unfortunately, there is no historical information available to evaluate the impacts on the total value of production and or the sustainability of the system in the long term.

5.2.5 Adaptive measures. Common adaptive strategies for the mitigation of droughts in the region are the use of wells, weirs and cisterns. Wells and weirs present the best impacts on agricultural production. For example, family farms D using weirs present a cattle production that is on average 15.7 per cent higher ($e^{0.146}-1$) than their counterparts (similar results are observed for family farms ABC). In turn, the use of cisterns, which is commonly used to supply water for human consumption, presents no positive impact on agricultural production. On the other hand, its negative impacts may indicate a specialization in subsistence activities, as cisterns have been implemented by public and private agencies in the poorer farms.

5.2.6 Market and credit. Specializing in few agricultural products has positive and substantial effects on all types of production and the impacts tend to be higher among non-family farms. For example, specialized dairy farming, that is, where the value of the milk production represents more than 65 per cent of the total agricultural production, presents a milk yield that is on average 41.9 per cent higher ($e^{0.350}-1$) among family farms D and 59.8 per cent higher ($e^{0.469}-1$) among non-family farms. The degree of integration with the market, i.e. the share of the total agricultural production commercialized in the market, also has a positive significant impact on all types of production. The impacts are larger on the milk farming, as farms with a regular supply of milk can obtain a fairer sale price. Integrated farms, where the ratio between the agricultural production and the revenue from agricultural production is greater than 0.5, present a milk production that is, on an average, 55.9 per cent higher ($e^{0.444}-1$) among family farms D, 56.8 per cent higher ($e^{0.450}-1$) among family farms ABC and 68.3 per cent higher ($e^{0.521}-1$) among non-family farms.

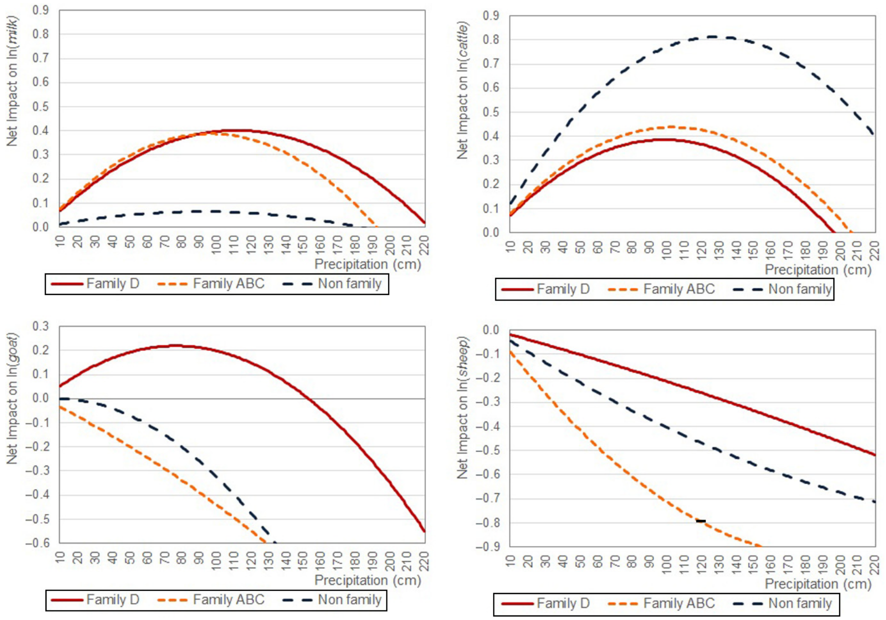
The access to agricultural credit showed negative impacts on the agricultural production. Two hypotheses may justify this result. First, the variable *credit* refers exclusively to the loans contracted in 2006 and may not account for positive impacts in the long run. Second, the effectiveness of PRONAF, the main credit program in the *Sertão*, tend to be strongly related to the level of local development (Maia *et al.*, 2016). In other words, PRONAF tends to fetch positive impacts in the more developed rural areas, although its effectiveness in the less developed areas is questionable.

5.2.7 Climate variables. Finally, the variables *avgtemp*, *precip* and $precip^2$ identify how the agricultural production of family and non-family farmers are affected by climate variables and therefore highlights farmers' vulnerability to climate change. The impacts of average temperature on agricultural production tend to be positive and stronger for family farms D. This trend among impoverished family farms may suggest a shift from traditional subsistence crops toward more resilient activities since the temperature has become warmer. The recent diffusion of cash transfer programs (*Bolsa Família*), which guarantee a minimum income for food security, mainly reinforce this trend, liberating the poorer farmers from subsistence crops.

The net impacts of precipitation are more significant in the cases of cattle and milk production. Figure 3 simulates the net impact of conditional levels of precipitation on the mean log of production using the estimates for the variables *precip* and $precip^2$ presented in Tables III and IV. The conditional values of precipitation range from 10 to 220 cm, the minimum and maximum values observed in 2005 and 2006. Results reinforce the idea that the production of goat and sheep, animals that are more resilient to droughts, tends to present a negative relation with precipitation. But these results must be interpreted carefully, as most estimates are not significant.

Average production of milk and cattle tends to rise sharply with a recorded precipitation level of around 100 cm, but production declines with an increased precipitation regime. For example, the milk production of those family farms in areas with average precipitation equal to 50 cm is between 8.5 per cent (for family farms ABC) and 11.1 per cent (for family farms D) lower than that of their peers in areas with average precipitation equal to 100 cm. The reduction after a certain level of precipitation (threshold) may probably reflect the shift toward more profitable activities, such as fruits, corn and cotton, the main local agricultural crops. Nonetheless, it must also be highlighted that the average values of precipitation observed in the *Sertão* is near to 90 cm.

The net impacts of precipitation on milk production and cattle herd are similar among family farms ABC and D. In the case of milk production, family farmers are more sensitive to precipitation levels than non-family farms. Large milk producers are well organized in this region and present relatively good socio-economic conditions. Moreover, the average number of cows used in the milk production is not large in this region (Table II), and non-



Source: Devised using data from Agricultural Census 2006

Figure 3. Net impact of precipitation on average log of production, 2006

family farmers can more easily finance the replacement of natural pasture by other forages (silage) as needed in more extreme climate conditions.

In the case of cattle herd, non-family farms are more sensitive to precipitation levels than family farms. In this case, the economic viability of large numbers of head in more extreme climatic conditions would depend fundamentally on the ability to provide food supplements (besides grass) within the farm (through forage). Small farmers have a relative advantage in this case, since they have a more favorable relation animal/labor force, which is essential to animal care and to maintain a sustainable area of forage in the farm. In addition, family farmers are more responsive because they usually live on the property while many non-family live in urban areas and the cattle is left grazing in the pasture with little control.

6. Conclusion

The climate change observed in the *Sertão* in the past 40 years is remarkable, confirming some of the most pessimistic scenarios for semi-arid regions in the world (Intergovernmental Panel on Climate Change, 2014). Average temperature has risen at a rate of 0.26°C per decade, and the maximum temperature shifted from an average of 30.0°C in the 1970s to 31.4°C in the 2010s. At the same time, the number of days without rain over the year increased from an average of 254 in the 1970s to 275 in the 2010s, and total precipitation reduced from 988 to 791 cm.

In response to increases in the average temperature, farmers tend to minimize risks and maximize profits by shifting to more resilient activities, such as cattle and milk farming (Deschenes and Greenstone, 2007; Mendelsohn *et al.*, 1994). The opportunity costs of small family farms are lower and they are more susceptible to shifts. The shift toward animal breeding is a trend that is also caused by economic forces. Milk and meat industries are keen to buy the products wherever those come from, while fruits and vegetables are perishable and cannot be easily commercialized to the national market without a well-founded infrastructure, which is not decidedly the case of the *Sertão*. The problem is that decreasing precipitation, occurring in parallel with rising temperatures, tends to reduce the low levels of productivity in this region even more.

A serious limitation of these analyses is that they do not account for short and medium run productive impacts caused by extreme droughts, which usually have devastating socioeconomic effects in the region. The intensity, frequency and duration of droughts on both livestock and primary agriculture production in the *Sertão* represent an important problem for future studies. Nonetheless, results emphasize that farmers' responses to warming conditions are also partly responsible for their misfortune in the long run, since raising livestock has been the main factor responsible for increase in greenhouse gas emission in Brazil (Silva *et al.*, 2017).

Several measures to boost agricultural production and mitigate the impacts of more extreme climate conditions have been targeted to small impoverished farmers in the region (Burney *et al.*, 2014; Cesano *et al.*, 2011). Mechanical technologies adapted to the semi-arid region can be used for both soil and rainwater management, and present positive impacts on all types of agricultural production. Technical guidance, which is still scarce, can help farmers to manage their establishments more efficiently during long periods of drought. The fertilization of pastures and crops can mitigate the soil aridification and have had relevant impacts on cattle and milk production. The control of diseases and parasites in animals also appears to be a key strategy for increasing cattle herds, although it may impact negatively on the milk yield in the short term. Wells and weirs are common strategies for drought mitigation in the region and present significant positive impacts on agricultural production. Policies of market integration are also relevant to stimulate some agricultural activities that are more market oriented in the region, especially milk.

The positive impacts of such characteristics on agricultural production provide important elements to address adaptive measures to the negative impacts of climate changes. Albeit still limited in the region, institutional policies aimed to promote access to education and technical guidance have showed significantly positive impacts on different types of production and should be prioritized, as well as measures to increase the technification of the production system or even the integration of family farmers in supply chains in the region. Cooperatives played important roles in providing technical assistance and promoting integration with the consumer market and revealed a positive impact on the cattle herd and milk yield in the region. Current credit system's coverage is very low and they are not generating the expected results in agriculture production as in other regions of the country (Maia *et al.*, 2016).

7. Policy implications

There is clearly a large spectrum for social and technical intervention in the *Sertão*. Besides climate risks, the characteristics of farms, farmers and their production systems reinforce the low productivity in this region. Policies of rural extension have had a limited range, as the percentage of producers receiving technical guidance for the production or credit-orientation is still low. Although family and non-family farms are roughly subject to the same climatic risks, small-scale with limited educational base are the most vulnerable groups in the region (Fraser, 2007; Simelton *et al.*, 2009). Among these, there is a yet more critical group, characterized by self-subsistence farming, with scarce access to technology and technical guidance.

Local, state and federal institutions should first identify the most vulnerable groups before implementing policies of climate resilience, followed by adaptation of resilience measures that already proved to be economically effective and efficient in the region. Based on the results presented in this study, a productive climate resilience reference system could generally be recommended. To improve the effectiveness of these measures, it would also be recommended to have a credit system oriented exclusively to finance the implementation of adaptive measures, technical assistance for its implementation, strengthening of cooperative institutions, agro-industrialization of products to add value to production and improving access to cross-scale markets.

Note

1. The average rate of variation r per decade for the climate variable X in each municipality was computed by the OLS estimator of $X_t = \alpha + r\,(t/10) + e_t$, where t is the year (t = 1.41).

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