Economic impacts of regional water scarcity in the São Francisco River Basin, Brazil: an application of a linked hydro-economic model

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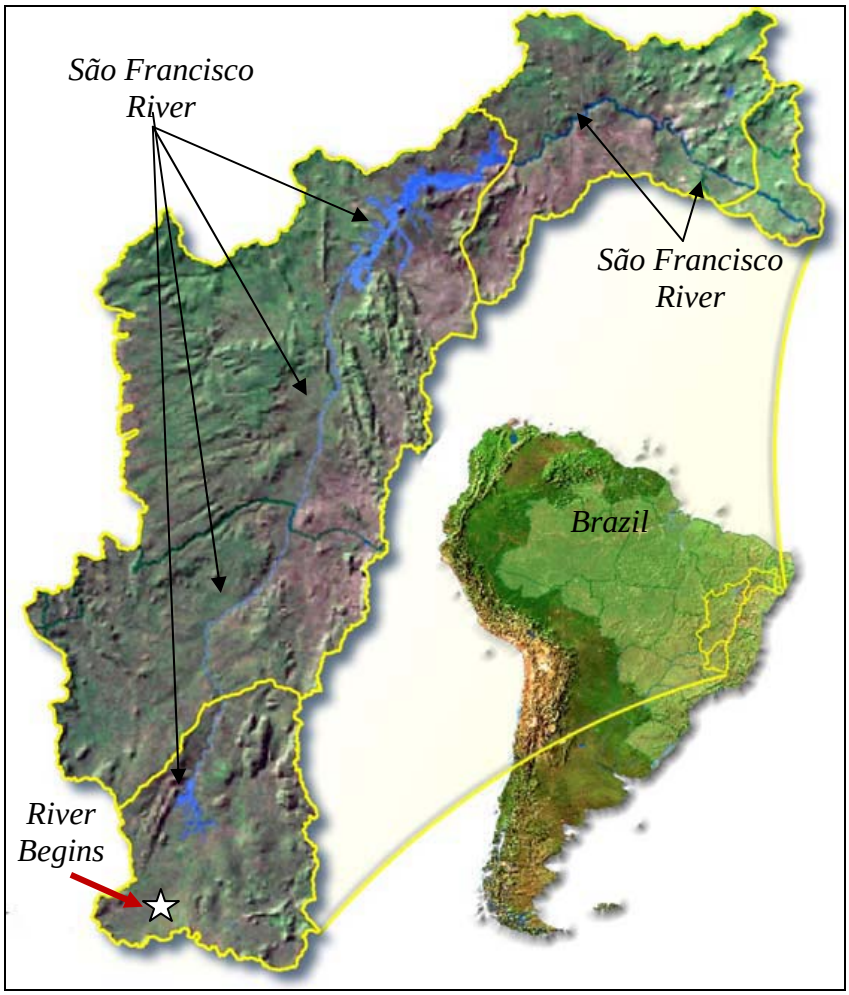
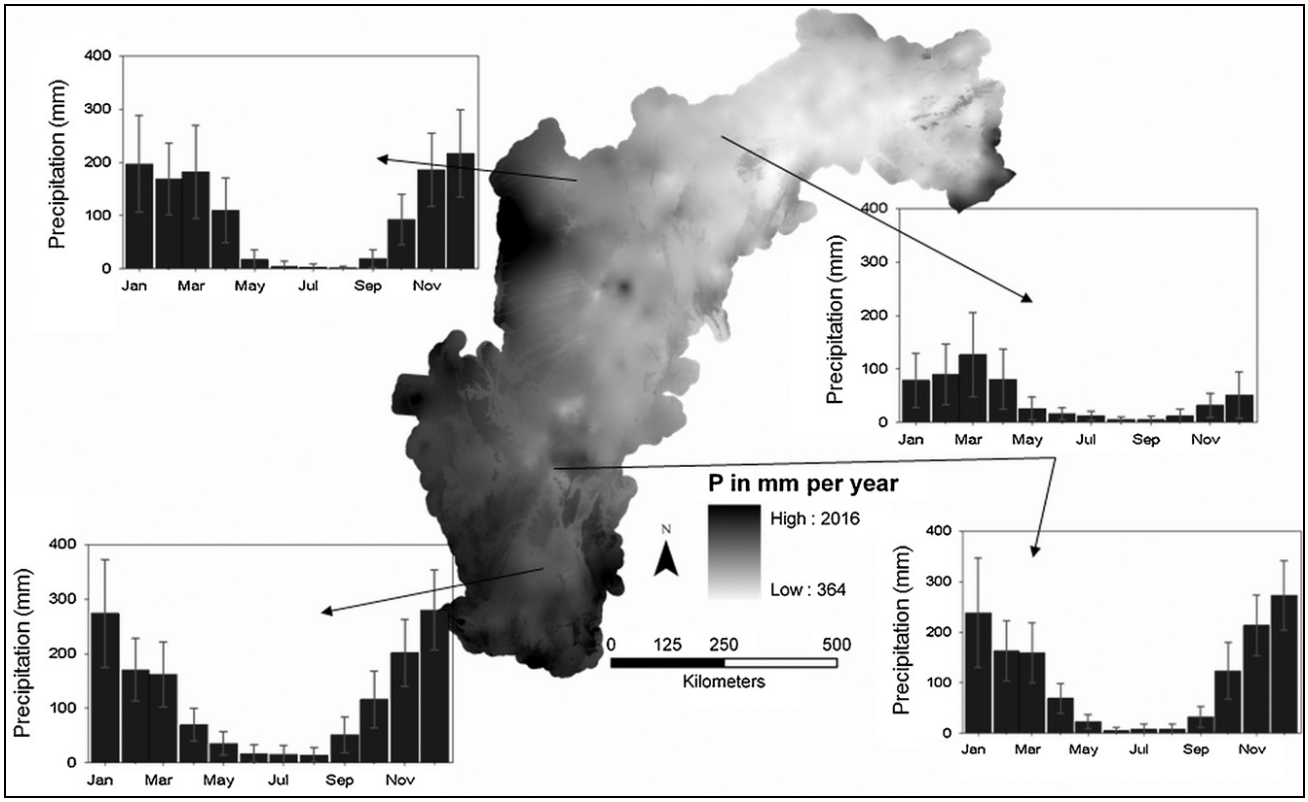
Appendix A – Figures and Tables

Brazil, the São Francisco River Basin and the São Francisco River



Average Annual Precipitation Across the SFRB and Seasonal Precipitation Patterns for Selected Sites



Source: Maneta *et al*., 2009

Production Function "Share" Parameter Values - Juazeiro Watershed, Selected Municípios and Crops[a]

		Inputs				
Municípios	***crops***	***land***	***sw***	***flabor***	***labor***	***mat***
Juazeiro	Pasture	0.5560				0.4440
Juazeiro	Sugarcane	0.6250	0.0010	0.0001	0.0770	0.2970
Petrolina	coconut (r)[b]	0.5630		0.0003	0.2460	0.1910
Petrolina	driedbeans	0.0040	0.0270	0.0002	0.1600	0.8090
America Dourada	corn (r)	0.3710		0.0010	0.1990	0.4290
Barra Do Mendes	Corn	0.2890	0.0130	0.0420	0.1420	0.5140
Barro Alto	vegetables(r)	0.9620		0.0002	0.0100	0.0270
Barro Alto	driedbeans	0.8060	0.0040	0.0010	0.0520	0.1380
Brotas De Macaubas	vegetables (r)	0.8410		0.0020	0.0570	0.1000
Brotas De Macaubas	Sugarcane	0.9750	0.0030	0.0003	0.0080	0.0140
Canarana	manioc (r)	0.6640		0.0020	0.1010	0.2340
Central	Soybeans	0.4750	0.0060	0.0040	0.1620	0.3530
Ibipeba	corn (r)	0.2090		0.0040	0.2310	0.5560
Ipupiara	Onions	0.8370	0.0060	0.0007	0.0340	0.1220
Irece	corn (r)	0.1800		0.0500	0.2550	0.5140
Itaguacu Da Bahia	mellon (r)	0.9260		0.0002	0.0190	0.0540
Joao Dourado	corn (r)	0.2930		0.0008	0.1970	0.5090
Casa Nova	vegetables (r)	0.9150		0.0002	0.0220	0.0630
Jussara	driedbeans	0.5460	0.0070	0.0140	0.1080	0.3240
Lapao	Pasture	0.6200				0.3800
Lapao	Sugarcane	0.7380	0.0050	0.0005	0.0800	0.1760
Buritirama	corn (r)	0.8260		0.0040	0.0090	0.1610
Mirangaba	Corn	0.4860	0.0070	0.1110	0.0990	0.2970
Morpara	corn (r)	0.5070		0.0006	0.0180	0.4740
Morro Do Chapeu	driedbeans (r)	0.4400		0.0010	0.2490	0.3100
Morro Do Chapeu	Mango	0.8670	0.0020	0.0002	0.0510	0.0810
Ourolandia	vegetables (r)	0.8910		0.0220	0.0140	0.0740
Ourolandia	sugarcane (r)	0.9720		0.0060	0.0040	0.0190
Presidente Dutra	driedbeans	0.6020	0.0050	0.0160	0.1530	0.2240
Presidente Dutra	Mango	0.8710	0.0020	0.0040	0.0770	0.0460
Remanso	driedbeans (r)	0.8270		0.0020	0.0360	0.1350
Remanso	Soybeans	0.7360	0.0090	0.0030	0.0540	0.1990
Campo Formoso	cotton (r)	0.5920		0.0030	0.2180	0.1870
Sao Gabriel	Corn	0.2020	0.0220	0.0030	0.1860	0.5870

[a] Parameter values calculated based on 1995/96 Brazilian Agricultural Census Data.
[b] (r) represents a rainfed crop.

Production Function "Share" Parameter Values - Boqueirão Watershed, Selected Municípios and Crops[a]

		Inputs				
Municípios	***crops***	***land***	***sw***	***flabor***	***labor***	***mat***
Angical	cotton (r)[b]	0.8660		0.0004	0.0160	0.1180
Angical	Corn	0.7820	0.0040	0.0006	0.0260	0.1870
Baianopolis	vegetables (r)	0.9100		0.0001	0.0080	0.0810
Baianopolis	driedbeans	0.6000	0.1840	0.0003	0.0200	0.1950
Barreiras	tomato (r)	0.6840		0.0000	0.0230	0.2930
Barreiras	soybeans	0.6070	0.0060	0.0000	0.0280	0.3590
Mansidao	corn (r)	0.5210		0.0008	0.0040	0.4740
Mansidao	Corn	0.6490	0.0050	0.0006	0.0030	0.3430
Catolandia	driedbeans (r)	0.5730		0.0020	0.0360	0.3890
Cotegipe	driedbeans (r)	0.3180		0.0004	0.1050	0.5770
Cotegipe	Onions	0.9010	0.0007	0.0001	0.0150	0.0830
Cotegipe	corn (r)	0.2940		0.2940	0.1170	0.2960
Cotegipe	soybeans	0.7710	0.0060	0.0930	0.0370	0.0940
Riachao Das Neves	soybeans (r)	0.5240		0.0001	0.0460	0.4300
Santa Rita De Cassia	manioc (r)	0.5710		0.0010	0.0860	0.3420
Santa Rita De Cassia	sugarcane	0.8140	0.0020	0.0005	0.0370	0.1470
Sao Desiderio	Corn	0.8860	0.0008	0.0000	0.0110	0.1030
Sao Desiderio	Tomato	0.9450	0.0003	0.0000	0.0050	0.0500
Wanderley	corn (r)	0.3720		0.0007	0.0590	0.5680
Wanderley	Rice	0.5850	0.0080	0.0005	0.0380	0.3690
Sao Domingos	rice (r)	0.2870		0.0001	0.0250	0.6880
Sao Domingos	corn	0.2780	0.0030	0.0001	0.0250	0.6930
Cristalandia Do Piaui	corn (r)	0.4640		0.2580	0.0900	0.1880
Cristalandia Do Piaui	driedbeans	0.2980	0.0960	0.2910	0.1020	0.2130

[a] Parameter values calculated based on 1995/96 Brazilian Agricultural Census Data.

[b] (r) represents a rainfed crop.

Output Quantities Data[a] for Selected Product - Juazeiro and Boqueirão

	Irrigated		*Rainfed*	
	Juazeiro	*Boqueirão*	*Juazeiro*	*Boqueirão*
Pasture	-	-	73796	116654
Manioc	-	-	77006	21560
Vegetables	-	-	69455	12293
Citrus	-	-	12895	12649
Mango	4727	1117	41692	9645
Tomato	3316	458	17466	2816
Dried Beans	24749	18373	32272	24843
Corn	4105	71456	33402	571374
Soybeans	-	80244	-	546330
Sugar Cane	10030	10556	12818	13550

(a) Crop production is reported in tons for all crops in the table but citrus and mango (thousand fruits); pasture production is reported in terms of the number of heads of cattle.

Output Prices Data[a] for Selected Products[a] - Juazeiro and Boqueirão

	Juazeiro	*Boqueirão*
Pasture	255	210
Manioc	176	167
Vegetables	225	417
Citrus	49	58
Mango	117	92
Tomato	269	343
Dried Beans	513	658
Corn	190	151
Soybeans	202	180
Sugar Cane	129	121

(a) Output prices per ton are presented in terms of 1995 Brazilian Reais (R$1=US$1), on average, at that time. For all crops, except pasture, citrus and mango, average prices are expressed on a per-ton basis. For pasture, the reported price is in terms of the average price per head; for citrus and mango, prices are per thousand fruits.

Input Quantity Data per Hectare, Selected Inputs and Crops – Juazeiro

	Land (hectares)	*Water per hectare (thousands m3)*	*Hired Labor per hectare (# of full-time + temporary workers)*	*Family Labor per hectare (# workers)*	*Materials per hectare (R$)* [a]
Manioc					
Rainfed	25820		0,1	0,4	76,0
Vegetables					
Rainfed	8067		0,1	0,3	321,2
Onions					
Rainfed	5606		0,3	0,5	469,7
Irrigated	412	5,0	0,3	0,5	420,8
Citrus					
Rainfed	523		0,4	0,8	516,8
Mango					
Rainfed	4561		0,4	0,8	604,6
Irrigated	239	11,2	0,4	0,8	607,2
Tomato					
Rainfed	1238		0,2	0,7	1188,3
Irrigated	86	12,8	0,3	0,7	1598,5
Dried Beans					
Rainfed	16076		0,7	2,9	823,8
Irrigated	45900	2,9	0,1	0,3	62,5
Corn					
Rainfed	63240		0,1	0,3	110,0
Irrigated	5373	8,9	0,1	0,3	69,4
Sugar Cane					
Rainfed	2605		0,2	0,3	944,3
Irrigated	778	16,8	0,2	0,3	1048,1
Pasture					
Rainfed	424203				17,9

[a] Materials expenditures are reported in terms of 1995 Brazilian reais; R$1=US$1, on average, at that time.

Input Quantity Data per Hectare, Selected Inputs and Crops – Boqueirão

	Land (hectares)	*Water per hectare (thousands m3)*	*Hired Labor per hectare (# of full-time + temporary workers)*	*Family Labor per hectare (# workers)*	*Materials per hectare (R$)* [a]
Manioc					
Rainfed	25820		0,04	0,00	145,68
Vegetables					
Rainfed	8067		0,02	0,11	185,20
Cotton					
Rainfed	5606		0,01	0,08	201,12
Rice	412				
Rainfed			0,01	0,05	199,02
Irrigated	523	4,2	0,01	0,05	199,04
Dried Beans					
Rainfed	4561		0,02	0,00	165,57
Irrigated	239	0,001	0,02	0,14	165,56
Corn					
Rainfed	1238		0,02	0,00	183,12
Irrigated	86	0,008	0,02	0,08	183,14
Soybeans					
Rainfed	16076		0,01	0,03	211,53
Irrigated	45900	2,0	0,01	0,03	3,47
Sugar Cane					
Rainfed	63240		0,03	0,34	131,39
Irrigated	5373	10,6	0,03	0,34	131,27
Pasture					
Rainfed	2605				78,86

[a]Materials expenditures are reported in terms of 1995 Brazilian reais; R$1=US$1, on average, at that time.

Baseline Monthly Water Availability in Juazeiro and Boqueirão under Wet (Optimistic) and Drought (Pessimistic) Weather Scenarios (Sugar Cane Prices Are as in the Baseline Year)

	Wet-Year (m^3/sec)		*Drought-Water (m^3/sec)*	
	Juazeiro	*Boqueirão*	*Juazeiro*	*Boqueirão*
January	5477	463	2992	220
February	5471	557	2955	168
March	5718	484	2365	210
April	3131	418	1578	221
May	1724	336	682	197
June	1574	287	274	177
July	13912	267	67	172
August	919	253	10	167
September	381	245	10	162
October	621	268	10	170
November	1740	320	628	195
December	3863	411	2154	219

Monthly Water Availability in Juazeiro during Wet (Optimistic) and Drought (Pessimistic) Weather Scenarios, Assuming the High -Sugar-Price Scenario

	Wet Year (m^3/sec)	*Drought Year (m^3/sec)*
January	5442	2973
February	5388	2927
March	5723	2154
April	3175	1585
May	1743	650
June	1483	222
July	1366	10
August	827	10
September	296	10
October	543	10
November	1718	574
December	3794	2016

Appendix B -Production Function Parameter Expressions

For rainfed crops

$$b_{i\,land} = b_{i\,labor}\frac{\lambda_{land} + \lambda_{i\overline{land}}}{p_{labor}}\left(\frac{X_{i\,labor}}{X_{i\,land}}\right)^{-\frac{1}{\sigma}} \quad \text{(A1)}$$

$$b_{i\ flabor} = b_{i\,labor}\frac{\lambda_{flabor}}{p_{labor}}\left(\frac{X_{i\,labor}}{X_{iflabor}}\right)^{-\frac{1}{\sigma}} \quad \text{(A2)}$$

$$b_{imat} = b_{i\,labor}\frac{p_{mat}}{p_{labor}}\left(\frac{X_{i\,labor}}{X_{i\,mat}}\right)^{-\frac{1}{\sigma}} \quad \text{(A3)}$$

$$b_{i\,labor} = 1 - b_{i\,land} - b_{iflabor} - b_{i\,mat}, \quad \text{(A4)}$$

where (A1) to (A4) are expressions for the production function parameters associated with land, family labor, materials and hired labor, respectively. (A4) is a result of the constant returns to scale assumption. $\lambda_{land}, \lambda_{flabor}$ are the shadow prices for land and family labor, respectively. $\lambda_{i\overline{land}}$ is the crop-specific La Grange multiplier associated with the calibration constraint.

By substituting (A1) – (A3) into (A4) , we can calculate the value for the hired labor parameter, $\hat{b}_{i\,labor}$. By plugging $\hat{b}_{i\,labor}$ back into (A1) – (A3), we can calculate the values of the remaining parameters, $\hat{b}_{i\,land}$, $\hat{b}_{i\ flabor}, \hat{b}_{i\,mat}$. Lastly, using (2), we have

$$\hat{A}_i = \frac{q_i^r}{\text{Precip}_i\left(\hat{b}_{i\,labor}X_{i\,labor}^{\ \gamma} + \hat{b}_{i\,land}X_{i\,land}^{\ \gamma} + \hat{b}_{i\ flabor}X_{iflabor}^{\ \gamma} + \hat{b}_{i\,mat}X_{imat}^{\ \gamma}\right)^{\frac{1}{\gamma}}} \quad \text{(A5)}$$

For irrigated crops

$$b_{i\,land} = b_{i\,labor}\frac{\lambda_{land} + \lambda_{i\overline{land}}}{p_{labor}}\left(\frac{X_{i\,labor}}{X_{i\,land}}\right)^{-\frac{1}{\sigma}} \quad \text{(A6)}$$

$$b_{i\ flabor} = b_{i\ labor}\frac{\lambda_{flabor}}{p_{labor}}\left(\frac{X_{i\ labor}}{X_{iflabor}}\right)^{-\frac{1}{\sigma}} \quad \text{(A7)}$$

$$b_{imat} = b_{i\ labor}\frac{p_{mat}}{p_{labor}}\left(\frac{X_{i\ labor}}{X_{i\ mat}}\right)^{-\frac{1}{\sigma}} \quad \text{(A8)}$$

$$b_{isw} = b_{i\ labor}\frac{\lambda_{sw}}{p_{labor}}\left(\frac{X_{i\ labor}}{X_{i\ sw}+P_i}\right)^{-\frac{1}{\sigma}} \quad \text{(A9)}$$

$$b_{i\ lb} = 1 - b_{i\ land} - b_{iflabor} - b_{is\ w} - b_{i\ mat}, \quad \text{(A10)}$$

where (A6) to (A10) are expressions for the irrigated crop production function parameters associated with land, family labor, materials, surface water, and hired labor, respectively. λ_{sw} is the shadow price of surface water, and $\lambda_{land}, \lambda_{flabor}$, $\lambda_{i\overline{land}}$ are defined as in the case of rainfed crop production, above. Lastly, using (3),

$$\hat{A}_i = \frac{q_i^{ir}}{(\hat{b}_{i\ labor}X_{i\ labor}{}^{\gamma} + \hat{b}_{i\ land}X_{i\ land}{}^{\gamma} + \hat{b}_{i\ mat}X_{i\ mat}{}^{\gamma} + \hat{b}_{i\ flabor}X_{i\ flabor}{}^{\gamma}\hat{b}_{i\ w}(X_{i\ sw}+P_i)^{\gamma})^{\frac{1}{\gamma}}}. \quad \text{(A11)}$$

Appendix C – Implicit Land Cost Function Parameter Expressions

By assuming perfect completion ($p_i = MC_i$), defining the elasticity of supply as $\eta_i = \frac{\partial q_i}{\partial p_i}\frac{p_i}{q_i}$, and defining the total cost of land allocated to crop *i* as the sum of the implicit and linear costs, $TCL_i = \alpha_i X_{i\,land} + 0.5\psi_i X_{iland}^2 + p_{land} X_{iland}$ we can derive an expression for the implicit cost of the land in terms of the parameters $\hat{\psi}_i$ and $\hat{\alpha}_i$. That is,

$$\hat{\psi}_i = \frac{1}{\eta_i}\frac{p_i}{X_{i\,land}} \quad , \tag{B1}$$

where η_i is the elasticity of supply for crop *i*, assumed to be equal to 2.5. Thus,

$$\hat{\alpha}_i = AC_i - 0.5\hat{\psi}_i X_{i\,land} - p_{land} \quad , \tag{B2}$$

where AC_i, the average cost of land, is defined to be the total average production cost (considering all inputs) reported by the famers minus the sum of average production costs of all inputs except land.

Appendix D – Database

In this appendix we define the procedures undertaken to collect and develop the necessary data to calibrate the economic model.

1. Crop Aggregation

Firstly, the crops are divided by the 1995/96 Census in the following categories: temporary crops; perennial crops; and vegetables. Once defined these basic categories, the most representative crops were selected considering the production within the SFRB. The criterion used was based on the total planted area and the estimated total water use of each one. Some of them remained aggregated in the census categories, while others were aggregated in a different way as follows: Driedbeans: 1°, 2° and 3° harvests; Forrages: *capim elefante, milho forrageiro, palma forrageira*, etc; Citrus: Orange, Lime, Lemon; Vegetables: Pineapple, pumpkins, zucchini, garlic, sweet potato, broccoli, cauliflower, lettuce, sweet pepper, carrot, etc.

Irrigated versus rainfed crops - The crops showed in the census as having a relatively large irrigated area were then put in the category of crops that can be irrigated or rainfed (banana, driedbeans, corn, grape, mango, melon, onion; Rice; Sugar Cane; Soybeans; Tomato). Those with very low or insignificant irrigated areas were considered as being purely rainfed (pasture; citrus; coconut; coffee; cotton; forages; manioc; and vegetables). The definition of the area and yield estimated for each one of these will be detailed below.

2. Output Quantities

The production quantity values used were collected using the SIDRA system (www.ibge.gov.br). For most of the crops the quantities are given for each *município* in tons. However, the measure units

for some of the crops are different: coconut, citrus, mango and melon are counted in “thousand fruits”, and bananas, in thousand bunches.

Missing values for quantities produced - Some crops in a few *municípios* presented missing data on quantity produced. These crops had values for planted area, usually smaller then 1ha, but had no number for the quantity produced. In order to avoid further problems, values from a different IBGE survey, PAM (Municipal Agricultural Production Survey) were used to replace the missing census values. Even after doing this procedure, there were still some cases with missing values, leading us to exclude the crops which had only information about planted area.

The production quantities were divided for the crops which had the irrigated and non-irrigated categories, using a yield estimation for each crop. The detailed estimation procedure is shown in the “yield” section below.

Livestock - The animal stock values are defined as the sum of sold animals (alive) and the slaughtered animals in the reference period, from 01/08/95 to 31/07/96. For livestock, we only considered cattle production since it is the only significant type of livestock in the region that uses a considerable amount of land for pasture growth.

3. Output Values

They are defined as the income from the selling of agricultural products and cattle.

4. Yield

The yields were calculated dividing the total crop production in each *município* by its total area. In very few cases, some yield values were excluded since they appeared to contain errors (e.g., being many times higher than the average yield for the region.) IBGE’s staff has confirmed that errors were possibly due to imprecision with very small area values. Note that in the Census quantities

harvested are not separated by irrigated and rainfed production. That is there is only the total quantity for each crop. To populate the model, we need to know the yield whether the crop is irrigated or dryland. We have then used differences in yield between dryland and irrigated production and applied these differences to disaggregate data. Differences in yield due to irrigation were based on interviews with technicians at the Brazilian Agricultural Research Corporation (EMBRAPA), Semi-Arid Tropics and Savannah Research Stations.

5. Output Prices

The Agricultural Census does not give direct information about output prices. They were estimated dividing the total crop value for each municipality by their total quantities produced. The prices received by the producers were considered to be the same for the irrigated and non-irrigated portions.

6. ***Input Quantities***

Materials - The materials category is an aggregation of the following inputs: fertilizers, pesticides, seeds, animal medicines, animal food, machine rental, transportation, fuel, sacks and packages, and electricity. The census doesn't disclose information on quantity measures for these inputs. Because of this, only expenditures (not quantities) were considered for these inputs.

The census gives only the expenditures by *município* for each kind of input, not being available the further division between the different crops. However, the input expenditures for each crop are available at the State level. To deal with the problem of lack of data at the *município* level, it was necessary to rely on some assumptions to get some useful data at a disaggregated level.

There were two options: 1) to assume that the State level input expenditure proportion for each crop is equal between *municípios*; or to assume that the input expenditure portions at the

município level are equal in a per-hectare comparison between crops in the same *município*. In the first case, we would derive different expenditures per hectare for each crop, but the total expenditures by *município* would then differ from the original census values. The second case would respect the municipal expenditures in the census, but would not account for differences between crops. This second option was chosen and the expenditures associated with each kind of input were distributed based on the planted areas, ignoring the kind of the crop.

Labor - The census gives the total number of employees in the farming activity (agriculture and animal production). These values are displayed in the Census in hired and family labor categories, allowing us to calculate their proportions for each *município*. The Census also gives the total labor used for agriculture specific for each *município* divided in three crop groups: temporary, perennial and vegetables. The proportion of family/hired labor in farming in a given *município* was then used to divide, between family and hired labor, the total labor used in each of these three crop groups. The total amounts of family and hired labor were then re-distributed to all crops following their land use proportion in each crop group.

Land – Area values refer to harvested area, in hectares for all crops. The production value and quantity are available in the census for vegetables but areas are nor. It was then necessary to estimate this area by dividing the total production quantity (Q) by the average yield (Y) of each vegetable (Area=Q/Y) collected through personal interviews with technicians from the Brazilian Agricultural Research Corporation (EMBRAPA) headquarters in Brasília. The land in pasture is defined as area planted for animal production, not included natural areas.

Irrigated Land - The Census considers as “irrigated” any area that has been irrigated using any method, not including the manual watering of plants. The total irrigated area by crop is available only at the State level. Then, the disaggregation to the *município* level was based on the average

proportion of the irrigated area by crop in each State (irrigated area in crop *i* divided by total harvested area of crop *i*). For example, suppose that this proportion associated to crop *i*, in the State *S* is *k*. If a given *município n* belongs to State *S*, the irrigated land allocated to crop *i* is calculates as the total harvested area of crop *i* in the *município* multiplied by *k*.

7. Input Prices

The only input with actual prices is hired labor. The others have information on total expenditures only. Hired labor was estimated as an average wage for each *município* dividing its total labor expenditure by the number of employees used in farming. This price is the same for all crops.

References

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