**CLIMATE CHANGES AND IMPACTS ON AGRICULTURE PRODUCTION IN SÃO PAULO-BRAZIL: APPLICATIONS OF SPATIAL PANEL DATA MODELS**

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São Paulo is the most populous and the richest state in Brazil, with 40 million people and 30% of total Brazilian GDP. Agriculture represents only 2% of the states’ GDP, but it plays a strategic role in the national trade balance. São Paulo is the leading producer of sugarcane/ethanol and a net exporter of coffee, fruits and meat. Extreme climate events have significantly affected the urban and rural economic activities, especially the severe droughts observed in the early 2010. We analyze the impacts of climate changes on the gross value of agricultural production (GVP) in São Paulo. Analyzes are based on a panel with data for 568 (historically comparable) municipalities between 1994 and 2014. Climate data were collected from conventional stations and interpolated across the state’s municipal areas using spatial interpolation techniques. We tested different specifications of spatial panel data models (SAR and SE models with fixed effects) to evaluate how variations in temperature and precipitation affect the GVP of permanent and temporary crops. Results indicate that spatial dependence is more significant in the models for permanent crops, since it reflects the existence of important spatial clusters of production, such as in the cases of fruits and coffee. In turn, the main temporary crops are present throughout the whole territory, namely sugarcane and corn. Increases in the average temperature and reduction in rainfall tend to affect negatively the GVP, and, most importantly, higher temperature variability tends to be the main villain of agriculture in São Paulo.

**Keywords:** climate change, agriculture, spatial autoregressive model, spatial error model, fixed effects estimation.

**Introduction**

**Methodology**

**Results and discussion**

|  |  |
| --- | --- |
| 1. **Average temperature (°C)** | 1. **Average temperature (sd) (°C)** |
|  |  |
| 1. **Number of days with less than 1 mm precipitation** | 1. **Number of days with precipitation exceeding 25 mm** |
|  |  |

**Figure 1. Trend of climatic variables in São Paulo state**

**Source: Research data interpolated from INMET meteorological stations.**

**Table 1. Growth rate of climatic variables by hydrographic basin**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Hydrographic Basin** | **Average temperature** | **Average temperature (sd)** | | **Precipitation<1mm** | | **Precipitation>25mm** |
| Aguapeí | -0.11% | 0.06% | -0.72% | | 0.00% | |
| Alto Paranapanema | 0.23% | 0.04% | -0.52% | | -0.17% | |
| Alto Tietê | 0.14% | 0.05% | -0.91% | | -0.65% | |
| Baixada Santista | 0.15% | 0.05% | -1.06% | | -0.73% | |
| Baixo Pardo/Grande | -0.06% | -0.23% | 0.23% | | -0.32% | |
| Baixo Tietê | -0.02% | -0.15% | -0.35% | | 0.16% | |
| Litoral Norte | -0.05% | 0.14% | 1.14% | | -1.12% | |
| Mantiqueira | -0.47% | 0.39% | 0.95% | | 3.91% | |
| Médio Paranapanema | -0.11% | 0.22% | -0.62% | | 0.64% | |
| Mogi | 0.04% | 0.01% | 0.27% | | -1.27% | |
| Paraíba do Sul | -0.08% | 0.04% | 0.40% | | -0.36% | |
| Pardo | -0.05% | 0.14% | 1.34% | | -1.64% | |
| Peixe | -0.12% | 0.20% | -1.44% | | 0.84% | |
| Piracicaba/Capivari/Jundiaí | 0.18% | 0.15% | -0.24% | | -1.06% | |
| Pontal do Paranapanema | -0.15% | 0.39% | -0.83% | | 1.42% | |
| Ribeira de Iguape/Litoral Sul | 0.20% | -0.17% | -0.36% | | -1.12% | |
| São José dos Dourados | 0.03% | -0.18% | -0.68% | | 0.35% | |
| Sapucaí/Grande | 0.12% | 0.07% | 0.67% | | -0.35% | |
| Tietê/Batalha | -0.08% | -0.25% | -0.62% | | -0.14% | |
| Tietê/Jacaré | 0.04% | -0.08% | -0.84% | | -0.76% | |
| Tietê/Sorocaba | 0.26% | 0.13% | -0.41% | | -1.49% | |
| Turvo/Grande | -0.01% | -0.31% | -0.24% | | -0.01% | |

**Source: Research data.**

**Figure 2. Gross value of permanent agricultural production (GVPAP) and gross value of temporary agricultural production (GVTAP) trends in São Paulo state.**

**Source: IBGE.**

**Table 2. Growth rates of GVPAP and GVTAP by hydrographic basin**

|  |  |  |
| --- | --- | --- |
| **Hydrographic Basin** | **GVPAP** | **GVTAP** |
| Aguapeí | 2.72% | 11.17% |
| Alto Paranapanema | 4.87% | 6.69% |
| Alto Tietê | 3.33% | -1.45% |
| Baixada Santista | 5.23% | 36.48% |
| Baixo Pardo/Grande | 2.37% | 4.47% |
| Baixo Tietê | -0.31% | 8.75% |
| Litoral Norte | -8.39% | -12.72% |
| Mantiqueira | 12.08% | 0.23% |
| Médio Paranapanema | 7.91% | 5.00% |
| Mogi | 2.78% | 2.81% |
| Paraíba do Sul | 3.17% | -1.09% |
| Pardo | 3.12% | 2.84% |
| Peixe | -1.58% | 9.36% |
| Piracicaba/Capivari/Jundiaí | 1.90% | 2.50% |
| Pontal do Paranapanema | 3.22% | 9.59% |
| Ribeira de Iguape/Litoral Sul | 5.68% | 5.27% |
| São José dos Dourados | 3.72% | 11.85% |
| Sapucaí/Grande | 5.74% | 3.86% |
| Tietê/Batalha | 2.18% | 7.97% |
| Tietê/Jacaré | 2.58% | 3.95% |
| Tietê/Sorocaba | 3.57% | 0.45% |
| Turvo/Grande | 2.06% | 8.43% |

**Source: Research data.**

**Table 3. Top 20 products of agricultural permanent production of São Paulo state**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Year** | **Main products** | **Value (in thousand R$)** | **% of total** | **Year** | **Main products** | **Value** | **% of total** |
| 1995 | Orange | 2,661,573 | 46.03% | 2014 | Orange | 3,656,572 | 42.71% |
| 1995 | Coffee | 1,423,195 | 24.61% | 2014 | Coffee | 1,599,072 | 18.68% |
| 1995 | Key lime | 473,784 | 8.19% | 2014 | Banana | 819,761 | 9.57% |
| 1995 | Tangerine | 351,191 | 6.07% | 2014 | Key lime | 529,517 | 6.18% |
| 1995 | Mango | 195,623 | 3.38% | 2014 | Grape | 404,653 | 4.73% |
| 1995 | Camellia sinensis (green tea) | 98,825 | 1.71% | 2014 | Rubber | 376,924 | 4.40% |
| 1995 | Passion fruit | 94,771 | 1.64% | 2014 | Palmetto | 293,068 | 3.42% |
| 1995 | Peach | 90,736 | 1.57% | 2014 | Tangerine | 230,615 | 2.69% |
| 1995 | Avocado | 84,899 | 1.47% | 2014 | Persimmon fruit | 143,084 | 1.67% |
| 1995 | Banana | 79,164 | 1.37% | 2014 | Mango | 119,010 | 1.39% |
| 1995 | Persimmon fruit | 72,786 | 1.26% | 2014 | Guava | 103,505 | 1.21% |
| 1995 | Grape | 61,533 | 1.06% | 2014 | Abacate | 75,774 | 0.88% |
| 1995 | Apple | 38,152 | 0.66% | 2014 | Avocado | 69,733 | 0.81% |
| 1995 | Fig | 31,380 | 0.54% | 2014 | Passion fruit | 39,911 | 0.47% |
| 1995 | Green papaya | 9,857 | 0.17% | 2014 | Fig | 34,166 | 0.40% |
| 1995 | Others | 15,082 | 0.26% | 2014 | others | 66,687 | 0.78% |
| 1995 | Total | 5,782,550 | 100.00% | 2014 | Total | 8,562,052 | 100.00% |

**Source: IBGE.**

**Table 4. Top 20 products of agricultural temporary production of São Paulo state**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Year** |  | **Main products** | | **Value (in thousand R$)** | **% of total** | **Year** | **Main products** | **Value** | **% of total** |
| 1995 |  | Sugar cane | | 7,178,284 | 52.47% | 2014 | Sugar cane | 21,417,289 | 74.69% |
| 1995 |  | Maize | 1,527,624 | | 11.17% | 2014 | Soybean | 1,708,017 | 5.96% |
| 1995 |  | Tomato | 1,020,193 | | 7.46% | 2014 | Tomato | 1,667,080 | 5.81% |
| 1995 |  | Potato | 913,797 | | 6.68% | 2014 | Maize | 1,538,610 | 5.37% |
| 1995 |  | Cassava | 626,000 | | 4.58% | 2014 | Potato | 505,920 | 1.76% |
| 1995 |  | Soybean | 598,933 | | 4.38% | 2014 | Peanut | 442,034 | 1.54% |
| 1995 |  | Cotton | 459,096 | | 3.36% | 2014 | Cassava | 414,290 | 1.44% |
| 1995 |  | Onion | 381,096 | | 2.79% | 2014 | Bean | 316,803 | 1.10% |
| 1995 |  | Bean | 378,596 | | 2.77% | 2014 | Onion | 158,149 | 0.55% |
| 1995 |  | Rice | 168,406 | | 1.23% | 2014 | Wheat | 134,014 | 0.47% |
| 1995 |  | Peanut | 154,446 | | 1.13% | 2014 | Watermelon | 119,426 | 0.42% |
| 1995 |  | Watermelon | 111,133 | | 0.81% | 2014 | Pineapple | 76,925 | 0.27% |
| 1995 |  | Sweep potato | 45,385 | | 0.33% | 2014 | Cotton | 55,618 | 0.19% |
| 1995 |  | Wheat | 39,905 | | 0.29% | 2014 | Sweep potato | 51,910 | 0.18% |
| 1995 |  | Pineapple | 33,730 | | 0.25% | 2014 | Rice | 44,738 | 0.16% |
| 1995 |  | Others | 44,255 | | 0.32% | 2014 | Others | 23,207 | 0.08% |
| 1995 |  | Total | 13,680,877 | | 100.00% | 2014 | Total | 28,674,030 | 100.00% |

**Source: IBGE.**

|  |  |  |
| --- | --- | --- |
| 1. GVPAP - 1995 |  | 1. GVPAP - 2014 |
|  |  |  |
| 1. GVTAP - 1995 |  | 1. GVTAP - 2014 |
|  |  |  |

**Figure 3. Proportional circles maps of GVPAP and GVTAP**

**Table 5. Effect of climate variables on gross value of permanent agricultural production (GVPAP)**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Independent variables** | **FE** | **FE + SAR** | **FE + SEM** | **FE + SAR + SEM** |
| rho | - | - | 0.1427 | -0.117 |
| (sigma) | - | - | 2.2390 | 2.2335 |
| Lambda | - | 0.2543\*\*\* | - | 0.2728\*\*\* |
|  | - | (0.0416) | - | (0.0388) |
| Average temperature | 0.1147\*\*\* | -0.0698\*\* | -0.0723\*\*\* | -0.0751\*\*\* |
|  | (0.0154) | (0.0223) | (0.0217) | (0.0222) |
| Average temperature (sd) | -0.2779\*\*\* | -0.7464\*\*\* | -0.7508\*\*\* | -0.7445\*\*\* |
|  | (0.0359) | (0.0739) | (0.0718) | (0.0736) |
| Precipitation<1mm | -0.0035\*\*\* | -0.0049\*\*\* | -0.0049\*\*\* | -0.0049\*\*\* |
|  | (0.0008) | (0.0013) | (0.0013) | (0.0013) |
| Precipitation>25mm | -0.012\*\*\* | -0.0114\*\* | -0.0118\*\* | -0.0112\*\* |
|  | (0.0018) | (0.0038) | (0.0036) | (0.0037) |
| Year | 0.0176\*\*\* | 0.1763\*\*\* | 0.0175\*\*\* | 0.0175\*\*\* |
|  | (0.0012) | (0.0026) | (0.0025) | (0.0026) |
| Mantiqueira | - | -1.4460\*\*\* | -1.5216\*\*\* | -1.4405\*\*\* |
|  | - | (0.2077) | (0.2036) | (0.2051) |
| Tietê/Sorocaba | - | -0.2890\*\* | -0.29475\*\* | -0.2803\*\* |
|  | - | (0.0985) | (0.0964) | (0.0975) |
| Ribeira de Iguape/Litoral Sul | - | 0.7638\*\*\* | 0.7548\*\*\* | 0.7650\*\*\* |
|  | - | (0.1055) | (0.1031) | (0.1046) |
| Baixo Pardo/Grande | - | 0.6786\*\*\* | 0.6931\*\*\* | 0.6728\*\*\* |
|  | - | (0.1310) | (0.1282) | (0.1298) |
| Tietê/Jacaré | - | 0.2724\*\* | 0.2771\*\*\* | 0.2682\*\* |
|  | - | (0.0847) | (0.0829) | (0.0013) |
| Alto Paranapanema | - | 0.4535\*\*\* | 0.4592\*\*\* | 0.4426\*\*\* |
|  | - | (0.0867) | (0.0850) | (0.0839) |
| Turvo/Grande | - | 0.5904\*\*\* | 0.5794\*\*\* | 0.6191\*\*\* |
|  | - | (0.0986) | (0.0963) | (0.0977) |
| Tietê/Batalha | - | 0.7748\*\*\* | 0.7647\*\*\* | 0.7760\*\*\* |
|  | - | (0.0991) | (0.0969) | (0.0982) |
| Médio Paranapanema | - | -0.7086\*\*\* | -0.7530\*\*\* | -0.6760\*\*\* |
|  | - | (0.0837) | (0.0821) | (0.0828) |
| São José dos Dourados | - | -0.0022 | -0.0036 | 0.0124 |
|  | - | (0.1186) | (0.1160) | (0.1174) |
| Baixo Tietê | - | -0.8272\*\*\* | -0.8436\*\*\* | -0.7924\*\*\* |
|  | - | (0.1056) | (0.1031) | (0.1048) |
| Paraíba do Sul | - | -2.5384\*\*\* | -2.5659\*\*\* | -2.5170\*\*\* |
|  | - | (0.0999) | (0.0976) | (0.0991) |
| Aguapeí | - | -0.5904\*\*\* | -0.6259\*\*\* | -0.5666\*\*\* |
|  | - | (0.1045) | (0.1021\_ | (0.1035) |
| Peixe | - | -0.9488\*\*\* | -0.9707\*\*\* | -0.9165\*\*\* |
|  | - | (0.1128) | (0.1105) | (0.1115) |
| Pontal do Paranapanema | - | -2.1277\*\*\* | -2.1706\*\*\* | -2.0969\*\*\* |
|  | - | (0.1277) | (0.1250) | (0.1264) |
| Pardo | - | 0.1812\* | 0.1906\* | 0.1847\* |
|  | - | (0.0942) | (0.0925) | (0.0930) |
| Alto Tietê | - | 0.6998\*\*\* | 0.7036\*\*\* | 0.6283\*\* |
|  | - | (0.2052) | (0.2000) | (0.2035) |
| Baixada Santista | - | 1.1248\*\*\* | 1.1514\*\*\* | 1.1338\*\*\* |
|  | - | (0.2481) | (0.2425) | (0.2459) |
| Sapucaí/Grande | - | -0.3389\*\* | -0.3422\*\* | -0.3508\*\* |
|  | - | (0.1106) | (0.1078) | (0.1098) |
| Mogi-Guaçu | - | 0.4944\*\*\* | 0.4684\*\*\* | 0.4961\*\*\* |
|  | - | (0.0827) | (0.0807) | (0.082) |

**Source: Research data.**

**Table 6. Effect of climate variables on gross value of temporary agricultural production (GVTAP)**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Independent variables** | **FE** | **FE + SAR** | **FE + SEM** | **FE + SAR + SEM** |
| rho | - | - | 0.0989 | 0.0546 |
| (sigma) | - | - | 1.7519 | 1.7548 |
| Lambda | - | 0.0462 ' | - | 0.0421 |
|  | - | (0.0270) | - | (0.0275) |
| Average temperature | -0.1181\*\*\* | 0.1221\*\*\* | 0.1186\*\*\* | 0.1198\*\*\* |
|  | (0.0302) | (0.0193) | (0.0188) | (0.0193) |
| Average temperature (sd) | -0.3266 | -0.1167 ' | -0.1158 ' | -0.1159 ' |
|  | (0.0302) | (0.0653) | (0.0632) | (0.0651) |
| Precipitation<1mm | -0.0067\*\*\* | -0.0011 | -0.0010 | -0.0010 |
|  | (0.0007) | (0.0012) | (0.0011) | (0.0012) |
| Precipitation>25mm | -0.0017 | 0.0089 | 0.0090 | 0.0090 |
|  | (0.0029) | (0.0066) | (0.0064) | (0.0066) |
| Year | 0.0581\*\*\* | 0.0593\*\*\* | 0.0595\*\*\* | 0.0595\*\*\* |
|  | (0.0010) | (0.0023) | (0.0022) | (0.0023) |
| Mantiqueira | - | -2.3021\*\*\* | -2.2998\*\*\* | -2.3011\*\*\* |
|  | - | (0.1826) | (0.1780) | (0.1828) |
| Tietê/Sorocaba | - | -0.0207 | -0.0296 | -0.0273 |
|  | - | (0.0799) | (0.0778) | (0.0800) |
| Ribeira de Iguape/Litoral Sul | - | -2.1754\*\*\* | -2.1777\*\*\* | -2.1787\*\*\* |
|  | - | (0.1012) | (0.0985) | (0.1012) |
| Baixo Pardo/Grande | - | 1.6981\*\*\* | 1.7039\*\*\* | 1.7034\*\*\* |
|  | - | (0.1108) | (0.1081) | (0.1110) |
| Tietê/Jacaré | - | 1.3362\*\*\* | 1.3541\*\*\* | 1.3484\*\*\* |
|  | - | (0.0728) | (0.0710) | (0.0729) |
| Alto Paranapanema | - | 0.9917\*\*\* | 0.9732\*\*\* | 0.9797\*\*\* |
|  | - | (0.0767) | (0.0710) | (0.0767) |
| Turvo/Grande | - | -0.1073 | -0.0963 | -0.0994 |
|  | - | (0.08297) | (0.0835) | (0.0857) |
| Tietê/Batalha | - | 0.1548 ' | 0.1607\* | 0.1595 ' |
|  | - | (0.0829) | (0.0807) | (0.0829) |
| Médio Paranapanema | - | 0.7232\*\*\* | 0.7334\*\*\* | 0.7313\*\*\* |
|  | - | (0.0729) | (0.0711) | (0.0730) |
| São José dos Dourados | - | -1.2144\*\*\* | -1.1992\*\*\* | -1.2037\*\*\* |
|  | - | (0.1025) | (0.0999) | (0.1026) |
| Baixo Tietê | - | 0.5241\*\*\* | 0.5558\*\*\* | 0.5448\*\*\* |
|  | - | (0.0919) | (0.0896) | (0.0920) |
| Paraíba do Sul | - | -1.9165\*\*\* | -1.9441\*\*\* | -1.9337\*\*\* |
|  | - | (0.0877) | (0.0855) | (0.0878) |
| Aguapeí | - | -0.4722\*\*\* | -0.4691\*\*\* | -0.4694\*\*\* |
|  | - | (0.0911) | (0.0889) | (0.0912) |
| Peixe | - | -0.2813\*\* | -0.2675\*\* | -0.2719\*\* |
|  | - | (0.0960) | (0.0938) | (0.0962) |
| Pontal do Paranapanema | - | 0.3744\*\*\* | 0.3689\*\*\* | 0.3712\*\*\* |
|  | - | (0.0989) | (0.0965) | (0.0990) |
| Pardo | - | 1.3777\*\*\* | 1.3649\*\*\* | 1.3722\*\*\* |
|  | - | (0.0816) | (0.0798) | (0.0818) |
| Alto Tietê | - | -1.2373\*\*\* | -1.2214\*\*\* | -1.2333\*\*\* |
|  | - | (0.2200) | (0.2146) | (0.2203) |
| Sapucaí/Grande | - | 1.1191\*\*\* | 1.1139\*\*\* | 1.1186\*\*\* |
|  | - | (0.0910) | (0.0885) | (0.0910) |
| Mogi-Guaçu | - | 1.1621\*\*\* | 1.1652\*\*\* | 1.1661\*\*\* |
|  | - | (0.0690) | (0.0672) | 0.0595 |

**Source: Research data.**

**Conclusion**

**References**

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