# Assessing the impact of agro-climatic factors and farm characteristics on the yield variation of the Norwegian fruit sector

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# Introduction I.

- Main drivers of ag. yields:
  - Technology
  - R&D (new hybrids etc.)
  - Weather
  - Etc.
- Common sense and anecdotal observations (remember the Tromsø presentation) revealed extreme events tended to impact wide geographic areas
- This was called the «systemic» nature of agriculture

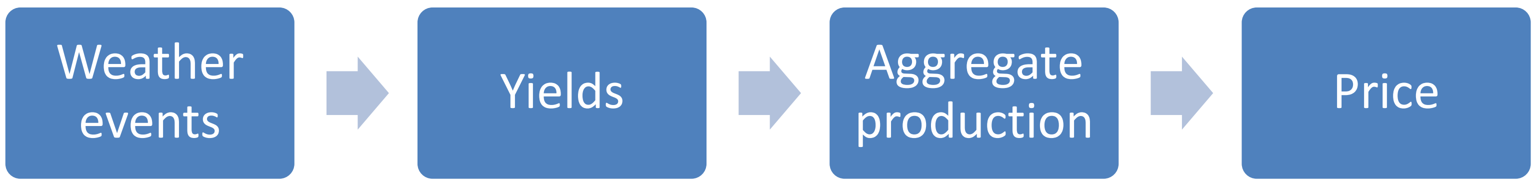
# Introduction II.

- Annual production shocks are driven by year-to-year weather variability (weather is in the production function)

-> identifying the drivers is well-researched, but little attention was payed which of these shocks aggregate up to a regional or national level

# Some Literature I.

- Goodwin (2015AmJAgricEcon) linked yield correlation to the weather and he found that weather events drive yields




- He examined this phenomenon by considering the relationship between geographical distance and linear Pearson correlation coefficient
- (it’s not a new thing, crop insurance economists use it all the time, but with his data he showed that the dependence concept lays under the observations*)

# Some Literature II.

- Tack and Holt (2016, ClimaticCh) found that spatial correlation roughly double in both good and bad years relative to normal years

  (important for climate change, food price volatility, crop insurance & yield modeling literature)
- They consider several functional forms for conditioning spatial correlations on weather and find that less flexible relationships generate misleading results

# Shortcomings

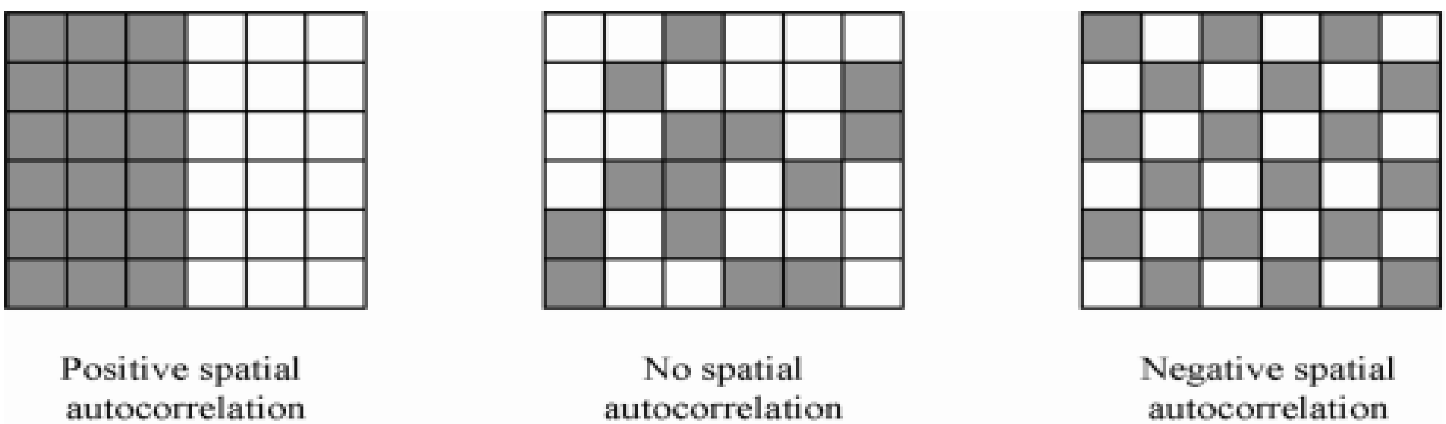
- Both papers uses *«a bit»* aggregated data
  - County level and state level, resp. (the reason is lacking data on the farm level)
  - Tack and Holt note that their regression framework could be generalized to county level which would cause larger cross-sections but smaller time-series dimension.
- Weather is measured as an aggregate index across several temperature and precipitation variables.
- As such, they cannot distinguish between the effects of draught versus extreme heat.
- However both have been found to be significant drivers of mean crop yields, and this likely extends to spatial yield correlations as well.
- Million dollar question: Which one induces larger changes in correlations than the other? They leave this open for future research

# Spatial autocorrelation I.

- Observations made at different locations might not be independent
- Assumption: measurements made at nearby locations may be closer in value than measurements made further apart
- On the term «autocorrelation»: correlation of a variable with itself

# Spatial autocorrelation II.

- Positive: when similar values occur near one another
- No: random locations (general assumption)
- Negative: dissimilar values occure near one another




Source: stolen from Google

# Let’s get the job done

- Need to define what is meant by two observations are close to each other, like a distance measure
- Called *«distance weight matrix»* which defines the relationships between locations where measurements are made (nxn)
- *Weight?!:* can be fixed (binary -> *k-nearest*) and weighted (inverse distance, raw standardized etc.)

# Moran's I

- Global spatial autocorrelation for continuous data
- It is based on cross-products of the deviations from the mean and is calculated for observations on a variable at locations *i, j* as:

$$I = \frac{n}{S_0} \frac{\sum_i \sum_j w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\sum_i (x_i - \bar{x})^2}$$

- -1/(n-1): expectation of MI tends to zero (in the absence of sp.corr.)
- Geary's C statistic (Geary 1954) is based on the deviations in responses of each observation with one another

# Norwegian fruit industry + poteter

- Farm-level horticulture data (farmers got subsidies after these registered volumes)
- 6 products:
  - Apple, pear merged (juice issue)
  - Plum
  - Potato
  - Strawberry
  - Other berries: BRINGEBÆR,SOLBÆR,RIPS,HAGEBLÅBÆR,STIKKELSBÆR

# Weight matrices

- Most controversial issue in spatial models
  (mostly arbitrary, usually not robust, BUT…)
- Systematic testing makes sense
- Keep it simple for now,
  - D- distance function: 10k, 20k, 30k, 40k, 50k
  - K- nearest neighbor function: 10

# Mean yields (kg/daa)

| | years | myapple | myplum | mycherries | myjordbar | myberr | mypoteter |
|---|---|---|---|---|---|---|---|
| 1 | 2002 | 781.3579 | 515.5554 | 254.5138 | 540.7011 | 569.7522 | 696.5924 |
| 2 | 2003 | 535.7069 | 363.8950 | 203.2240 | 378.6443 | 976.6095 | 935.2527 |
| 3 | 2004 | 686.0725 | 435.9162 | 316.6032 | 518.1105 | 565.9223 | 675.3845 |
| 4 | 2005 | 466.0768 | 333.7572 | 243.4731 | 507.2534 | 579.9146 | 731.1029 |
| 5 | 2006 | 691.2889 | 412.6428 | 382.6622 | 513.8112 | 592.5815 | 761.0512 |
| 6 | 2007 | 492.1494 | 386.6293 | 231.1586 | 488.1710 | 540.8959 | 738.2663 |
| 7 | 2008 | 758.6769 | 348.1263 | 285.9190 | 517.5416 | 519.7586 | 953.3275 |
| 8 | 2009 | 580.6163 | 353.3447 | 348.3503 | 502.9935 | 682.4938 | 660.3078 |
| 9 | 2010 | 619.0466 | 352.9828 | 269.5453 | 526.1208 | 568.1885 | 644.4539 |
| 10 | 2011 | 629.3266 | 309.8652 | 303.5072 | 441.4283 | 564.4568 | 667.7827 |
| 11 | 2012 | 424.1327 | 174.9376 | 183.0325 | 308.3281 | 331.5462 | 332.0094 |
| 12 | 2013 | 569.8520 | 150.4696 | 194.9988 | 417.3259 | 357.0988 | 492.0783 |
| 13 | 2014 | 424.1954 | 183.5525 | 208.6980 | 156.0542 | 231.8563 | 309.6877 |
| 14 | 2015 | 1027.0227 | 320.7684 | 508.4455 | 414.9164 | 616.1209 | 749.3386 |

# DOES THE DATA EXHIBIT SPATIAL AUTOCORRELATION OR NOT?

- If not, go on with the standard non-spatial models
- If so, then formulate spatial models

Table 1: Spatial correlation of APPLE

| | years | d10 | d20 | d30 | d40 | d50 | k10 |
|---|---|---|---|---|---|---|---|
| 1 | 2002 | -0.028 | -0.026 | -0.020 | 0.022 . | -0.020 | -0.014 |
| 2 | 2003 | 0.122 *** | 0.088 *** | 0.089 *** | 0.086 *** | 0.091 *** | 0.192 *** |
| 3 | 2004 | 0.090 *** | 0.059 *** | 0.051 *** | 0.047 *** | 0.052 *** | 0.128 *** |
| 4 | 2005 | 0.132 *** | 0.083 *** | 0.087 *** | 0.080 *** | 0.085 *** | 0.187 *** |
| 5 | 2006 | 0.061 *** | 0.038 *** | 0.045 *** | 0.042 *** | 0.045 *** | 0.085 *** |
| 6 | 2007 | 0.043 ** | 0.017 . | 0.015 * | 0.011 * | 0.000 | 0.090 *** |
| 7 | 2008 | 0.051 *** | 0.017 * | 0.031 *** | 0.027 *** | 0.022 *** | 0.089 *** |
| 8 | 2009 | 0.035 * | -0.015 | -0.007 | 0.000 | -0.000 | 0.061 *** |
| 9 | 2010 | 0.047 ** | 0.027 * | 0.035 *** | 0.036 *** | 0.030 *** | 0.085 *** |
| 10 | 2011 | 0.134 *** | 0.072 *** | 0.084 *** | 0.079 *** | 0.090 *** | 0.152 *** |
| 11 | 2012 | 0.405 *** | 0.334 *** | 0.355 *** | 0.355 *** | 0.363 *** | 0.437 *** |
| 12 | 2013 | 0.283 *** | 0.215 *** | 0.230 *** | 0.234 *** | 0.219 *** | 0.307 *** |
| 13 | 2014 | 0.208 *** | 0.153 *** | 0.165 *** | 0.164 *** | 0.152 *** | 0.261 *** |
| 14 | 2015 | 0.081 *** | 0.067 *** | 0.067 *** | 0.071 *** | 0.061 *** | 0.110 *** |

# Mean yields (kg/daa)

| | years | myapple | myplum | mycherries | myjordbar | myberr | mypoteter |
|---|---|---|---|---|---|---|---|
| 1 | 2002 | 781.3579 | 515.5554 | 254.5138 | 540.7011 | 569.7522 | 696.5924 |
| 2 | 2003 | 535.7069 | 363.8950 | 203.2240 | 378.6443 | 976.6095 | 935.2527 |
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| 7 | 2008 | 758.6769 | 348.1263 | 285.9190 | 517.5416 | 519.7586 | 953.3275 |
| 8 | 2009 | 580.6163 | 353.3447 | 348.3503 | 502.9935 | 682.4938 | 660.3078 |
| 9 | 2010 | 619.0466 | 352.9828 | 269.5453 | 526.1208 | 568.1885 | 644.4539 |
| 10 | 2011 | 629.3266 | 309.8652 | 303.5072 | 441.4283 | 564.4568 | 667.7827 |
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| 12 | 2013 | 569.8520 | 150.4696 | 194.9988 | 417.3259 | 357.0988 | 492.0783 |
| 13 | 2014 | 424.1954 | 183.5525 | 208.6980 | 156.0542 | 231.8563 | 309.6877 |
| 14 | 2015 | 1027.0227 | 320.7684 | 508.4455 | 414.9164 | 616.1209 | 749.3386 |

Table 1: Spatial correlation of PLUM

| | years | d10 | d20 | d30 | d40 | d50 | k10 |
|---|---|---|---|---|---|---|---|
| 1 | 2002 | -0.062 | -0.008 | -0.011 | -0.014 | -0.007 | 0.014 |
| 2 | 2003 | 0.109 *** | 0.044 *** | 0.018 . | 0.014 . | 0.015 . | 0.172 *** |
| 3 | 2004 | 0.084 *** | 0.053 *** | 0.040 *** | 0.030 ** | 0.029 ** | 0.158 *** |
| 4 | 2005 | 0.241 *** | 0.165 *** | 0.151 *** | 0.139 *** | 0.134 *** | 0.224 *** |
| 5 | 2006 | 0.052 ** | -0.001 | 0.000 | 0.007 | 0.003 | 0.154 *** |
| 6 | 2007 | 0.173 *** | 0.140 *** | 0.131 *** | 0.122 *** | 0.127 *** | 0.190 *** |
| 7 | 2008 | 0.043 * | -0.003 | -0.005 | -0.001 | -0.017 | 0.125 *** |
| 8 | 2009 | 0.137 *** | 0.134 *** | 0.147 *** | 0.151 *** | 0.153 *** | 0.176 *** |
| 9 | 2010 | 0.039 * | 0.008 | 0.025 * | 0.026 * | 0.023 * | 0.071 *** |
| 10 | 2011 | 0.087 *** | 0.087 *** | 0.111 *** | 0.103 *** | 0.086 *** | 0.108 *** |
| 11 | 2012 | 0.223 *** | 0.240 *** | 0.318 *** | 0.308 *** | 0.294 *** | 0.281 *** |
| 12 | 2013 | 0.308 *** | 0.309 *** | 0.293 *** | 0.289 *** | 0.299 *** | 0.280 *** |
| 13 | 2014 | 0.048 * | 0.035 * | 0.007 | -0.011 | 0.043 ** | 0.067 ** |
| 14 | 2015 | 0.111 *** | 0.048 ** | 0.086 *** | 0.086 *** | 0.087 *** | 0.146 *** |

# Mean yields (kg/daa)

| | years | myapple | myplum | mycherries | myjordbar | myberr | mypoteter |
|---|---|---|---|---|---|---|---|
| 1 | 2002 | 781.3579 | 515.5554 | 254.5138 | 540.7011 | 569.7522 | 696.5924 |
| 2 | 2003 | 535.7069 | 363.8950 | 203.2240 | 378.6443 | 976.6095 | 935.2527 |
| 3 | 2004 | 686.0725 | 435.9162 | 316.6032 | 518.1105 | 565.9223 | 675.3845 |
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| 8 | 2009 | 580.6163 | 353.3447 | 348.3503 | 502.9935 | 682.4938 | 660.3078 |
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| 13 | 2014 | 424.1954 | 183.5525 | 208.6980 | 156.0542 | 231.8563 | 309.6877 |
| 14 | 2015 | 1027.0227 | 320.7684 | 508.4455 | 414.9164 | 616.1209 | 749.3386 |

Table 1: Spatial correlation of CHERRIES

| | years | d10 | d20 | d30 | d40 | d50 | k10 |
|---|---|---|---|---|---|---|---|
| 1 | 2002 | 0.035 | 0.068 | 0.064 . | 0.06555 . | 0.066 * | 0.016 |
| 2 | 2003 | 0.248 *** | 0.222 *** | 0.220 *** | 0.21870 *** | 0.204 *** | 0.197 *** |
| 3 | 2004 | 0.201 *** | 0.194 *** | 0.171 *** | 0.15740 *** | 0.147 *** | 0.153 *** |
| 4 | 2005 | 0.281 *** | 0.244 *** | 0.199 *** | 0.23496 *** | 0.208 *** | 0.243 *** |
| 5 | 2006 | 0.253 *** | 0.229 *** | 0.159 *** | 0.14403 *** | 0.142 *** | 0.191 *** |
| 6 | 2007 | 0.097 ** | 0.113 *** | 0.067 *** | 0.04972 ** | 0.036 * | 0.005 |
| 7 | 2008 | 0.290 *** | 0.291 *** | 0.296 *** | 0.32078 *** | 0.312 *** | 0.327 *** |
| 8 | 2009 | 0.370 *** | 0.325 *** | 0.310 *** | 0.30456 *** | 0.277 *** | 0.264 *** |
| 9 | 2010 | 0.360 *** | 0.375 *** | 0.368 *** | 0.29427 *** | 0.271 *** | 0.351 *** |
| 10 | 2011 | 0.243 *** | 0.241 *** | 0.252 *** | 0.19763 *** | 0.157 *** | 0.264 *** |
| 11 | 2012 | 0.256 *** | 0.258 *** | 0.301 *** | 0.25503 *** | 0.230 *** | 0.277 *** |
| 12 | 2013 | 0.492 *** | 0.298 *** | 0.314 *** | 0.23843 *** | 0.255 *** | 0.289 *** |
| 13 | 2014 | 0.472 *** | 0.425 *** | 0.414 *** | 0.37997 *** | 0.378 *** | 0.388 *** |
| 14 | 2015 | 0.030 | 0.011 | 0.024 | 0.00068 | -0.025 | 0.031 |

# Mean yields (kg/daa)

| | years | myapple | myplum | mycherries | myjordbar | myberr | mypoteter |
|---|---|---|---|---|---|---|---|
| 1 | 2002 | 781.3579 | 515.5554 | 254.5138 | 540.7011 | 569.7522 | 696.5924 |
| 2 | 2003 | 535.7069 | 363.8950 | 203.2240 | 378.6443 | 976.6095 | 935.2527 |
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| 5 | 2006 | 691.2889 | 412.6428 | 382.6622 | 513.8112 | 592.5815 | 761.0512 |
| 6 | 2007 | 492.1494 | 386.6293 | 231.1586 | 488.1710 | 540.8959 | 738.2663 |
| 7 | 2008 | 758.6769 | 348.1263 | 285.9190 | 517.5416 | 519.7586 | 953.3275 |
| 8 | 2009 | 580.6163 | 353.3447 | 348.3503 | 502.9935 | 682.4938 | 660.3078 |
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| 13 | 2014 | 424.1954 | 183.5525 | 208.6980 | 156.0542 | 231.8563 | 309.6877 |
| 14 | 2015 | 1027.0227 | 320.7684 | 508.4455 | 414.9164 | 616.1209 | 749.3386 |

Table 1: Spatial correlation of STRAWBERRY

| | years | d10 | d20 | d30 | d40 | d50 | k10 |
|---|---|---|---|---|---|---|---|
| 1 | 2002 | 0.063 | 0.0617 | 0.015 | -0.005 | -0.004 | -0.009 |
| 2 | 2003 | 0.173 *** | 0.1158 *** | 0.094 *** | 0.0775 *** | 0.0543 ** | 0.158 *** |
| 3 | 2004 | 0.284 *** | 0.2303 *** | 0.200 *** | 0.1681 *** | 0.1591 *** | 0.247 *** |
| 4 | 2005 | 0.361 *** | 0.3374 *** | 0.310 *** | 0.2928 *** | 0.2470 *** | 0.344 *** |
| 5 | 2006 | 0.256 *** | 0.2447 *** | 0.213 *** | 0.2072 *** | 0.1879 *** | 0.248 *** |
| 6 | 2007 | 0.238 *** | 0.2422 *** | 0.217 *** | 0.2315 *** | 0.2087 *** | 0.271 *** |
| 7 | 2008 | 0.318 *** | 0.3232 *** | 0.275 *** | 0.2637 *** | 0.2193 *** | 0.295 *** |
| 8 | 2009 | 0.306 *** | 0.2550 *** | 0.198 *** | 0.2014 *** | 0.1731 *** | 0.203 *** |
| 9 | 2010 | 0.076 | 0.0095 | -0.021 | -0.029 | -0.014 | 0.029 |
| 10 | 2011 | 0.227 ** | 0.1805 *** | 0.190 *** | 0.1727 *** | 0.1288 *** | 0.214 *** |
| 11 | 2012 | 0.195 ** | 0.0877 . | 0.177 *** | 0.1925 *** | 0.1750 *** | 0.168 *** |
| 12 | 2013 | 0.126 * | 0.1310 ** | 0.158 *** | 0.1571 *** | 0.1344 *** | 0.186 *** |
| 13 | 2014 | 0.083 | 0.0197 | 0.026 | 0.0084 | 0.0081 | -0.011 |
| 14 | 2015 | 0.201 ** | 0.0908 . | 0.108 * | 0.0761 * | 0.0518 . | 0.066 * |

# Mean yields (kg/daa)

| | years | myapple | myplum | mycherries | myjordbar | myberr | mypoteter |
|---|---|---|---|---|---|---|---|
| 1 | 2002 | 781.3579 | 515.5554 | 254.5138 | 540.7011 | 569.7522 | 696.5924 |
| 2 | 2003 | 535.7069 | 363.8950 | 203.2240 | 378.6443 | 976.6095 | 935.2527 |
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| 8 | 2009 | 580.6163 | 353.3447 | 348.3503 | 502.9935 | 682.4938 | 660.3078 |
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| 14 | 2015 | 1027.0227 | 320.7684 | 508.4455 | 414.9164 | 616.1209 | 749.3386 |

Table 1: Spatial correlation of BERRIES

| | years | d10 | d20 | d30 | d40 | d50 | k10 |
|---|---|---|---|---|---|---|---|
| 1 | 2002 | 0.0729 | 0.022 | 0.005 | -0.031 | 0 | 0.0037 |
| 2 | 2003 | 0.0079 | -0 | -0 | -0 | -0 | -0 |
| 3 | 2004 | 0.3643 *** | 0.330 *** | 0.337 *** | 0.312 *** | 0.326 *** | 0.4091 *** |
| 4 | 2005 | 0.2058 *** | 0.233 *** | 0.248 *** | 0.253 *** | 0.253 *** | 0.2781 *** |
| 5 | 2006 | 0.1913 *** | 0.193 *** | 0.195 *** | 0.179 *** | 0.180 *** | 0.2245 *** |
| 6 | 2007 | 0.1699 *** | 0.230 *** | 0.227 *** | 0.211 *** | 0.198 *** | 0.1973 *** |
| 7 | 2008 | 0.1699 *** | 0.207 *** | 0.210 *** | 0.228 *** | 0.254 *** | 0.2069 *** |
| 8 | 2009 | 0.1309 ** | 0.095 ** | 0.099 *** | 0.115 *** | 0.161 *** | 0.1669 *** |
| 9 | 2010 | 0.2234 *** | 0.239 *** | 0.249 *** | 0.248 *** | 0.278 *** | 0.2744 *** |
| 10 | 2011 | 0.0555 . | 0.099 *** | 0.086 *** | 0.073 *** | 0.069 *** | 0.0572 ** |
| 11 | 2012 | 0.1978 *** | 0.180 *** | 0.152 *** | 0.104 *** | 0.083 ** | 0.1279 *** |
| 12 | 2013 | 0.1596 ** | 0.145 *** | 0.157 *** | 0.134 *** | 0.089 *** | 0.0853 *** |
| 13 | 2014 | 0.3449 *** | 0.320 *** | 0.332 *** | 0.302 *** | 0.280 *** | 0.3108 *** |
| 14 | 2015 | 0.2166 *** | 0.230 *** | 0.219 *** | 0.226 *** | 0.215 *** | 0.2071 *** |

# Mean yields (kg/daa)

| | years | myapple | myplum | mycherries | myjordbar | myberr | mypoteter |
|---|---|---|---|---|---|---|---|
| 1 | 2002 | 781.3579 | 515.5554 | 254.5138 | 540.7011 | 569.7522 | 696.5924 |
| 2 | 2003 | 535.7069 | 363.8950 | 203.2240 | 378.6443 | 976.6095 | 935.2527 |
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| 5 | 2006 | 691.2889 | 412.6428 | 382.6622 | 513.8112 | 592.5815 | 761.0512 |
| 6 | 2007 | 492.1494 | 386.6293 | 231.1586 | 488.1710 | 540.8959 | 738.2663 |
| 7 | 2008 | 758.6769 | 348.1263 | 285.9190 | 517.5416 | 519.7586 | 953.3275 |
| 8 | 2009 | 580.6163 | 353.3447 | 348.3503 | 502.9935 | 682.4938 | 660.3078 |
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Table 1: Spatial correlation of POTATOE

| | years | d10 | d20 | d30 | d40 | d50 | k10 |
|---|---|---|---|---|---|---|---|
| 1 | 2002 | -0.055 | -0.072 | -0.094 | -0.064 | -0.041 | -0.075 |
| 2 | 2003 | -0.027 | 0.042 | 0.027 | 0.0292 | 0.0198 | 0.000 |
| 3 | 2004 | 0.1676 . | 0.146 * | 0.125 * | -0.022 | -0.107 | 0.076 ** |
| 4 | 2005 | -0.064 | -0.165 | -0.154 | -0.156 | -0.142 | -0.004 |
| 5 | 2006 | 0.0028 | 0.010 | 0.031 | 0.0365 | 0.0212 | -0.019 |
| 6 | 2007 | 0.0496 | 0.174 * | 0.205 * | 0.2106 ** | 0.1666 ** | 0.029 |
| 7 | 2008 | -0.047 | 0.015 | 0.012 | 0.0091 | 0.0064 | -0.023 |
| 8 | 2009 | -0.060 | -0.089 | -0.064 | -0.093 | -0.071 | 0.009 |
| 9 | 2010 | 0.2184 . | 0.376 ** | 0.360 ** | 0.2491 * | 0.0775 | 0.034 |
| 10 | 2011 | 0.0616 | -0.133 | -0.120 | -0.122 | -0.109 | -0.085 |
| 11 | 2012 | 0.0132 | -0.148 | -0.198 | -0.181 | -0.173 | -0.091 |
| 12 | 2013 | 0.1872 . | 0.121 | 0.144 . | 0.1328 * | 0.1170 * | 0.116 ** |
| 13 | 2014 | 0.1996 | 0.375 ** | 0.338 ** | 0.2790 * | 0.1683 . | 0.094 * |
| 14 | 2015 | 0.1290 | 0.132 | 0.012 | 0.0922 | 0.0436 | -0.032 |

# Set up spatial models

- Linear-in-parameters CS model: $y = X\beta + u$
- SAR: $y = \lambda W y + X\beta + u$
- SEM: $$\begin{aligned} y &= X\beta + u \\ u &= \rho W u + v \end{aligned}$$
- SDM: $y = \rho W y + x(\beta + \gamma) + W x(-\rho\beta) + v$

# Contribution

- No semi-aggregation → farm-level
- Not the boring corn, maize, wheat → fruits
- No OLS-like Pearson correlation or functional form approach for conditioning spatial correlations on weather → SDM
- Finally, if we are smart enough to set the explanatory proxies in a meaningful way presumably we can make the distinction between the effects of, say draught and extreme heat.
- And much more in policy relevance