Land, Sea, and Economic Transition: Spatial Analysis at the Grid Cell Level

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What causes differences in worldwide incomes?

• two ways to explain cross country differences in income
  – savings, population, human capital, technology, etc.
    • These variables explain most of the variation.
  – starting dates for economic growth
    • The best explanation is simply the timing of growth’s take-off.

• determinants of timing
  – institutions
  – geography
    • the subject of this research
geography and agriculture

• How can geography explain labor’s release from agriculture?
  – Following Gollin et al. (2002)
    • Non-homothetic food preferences (Engel’s Law)
    • technology raises per-worker output over time
    • preferences are finally satisfied after \( t = 1,2\ldots n \) iterations when:
      \[
      A(1+\gamma)^t L = f
      \]
    • Workers exit agriculture \textbf{and} transition commences.
  – TFP parameter \( A \) is a function of institutions and geography.
geography and manufacturing

• Firms won’t produce if transport costs are high.
  • Firms face fixed capital input $K$, transport distance $d$, and per-distance costs $t$.
    $$\pi = (p-td)Y-wL-rK$$
  • Raising transport costs reduces the profitable range of fixed capital input $K_{max}$.
    $$\frac{\partial K_{max}}{\partial td} < 0$$
    • If $K_{max} < K$ then the firm does not produce.

• Transition begins earlier if
  • population density in the home market is large.
  • access to distant markets is cheap.
empirical approach: data

- worldwide grid cell data
  - dimensions
    - 0.5° x 0.5° latitude-longitude
    - ≈1,860 square miles at the equator
  - advantages of the grid cell approach
    - micro-scale
      - larger n
      - captures variation within countries
    - regular geographic units
      - independent of country and administrative boundaries
        - permits an examination of geographic effects without the potentially confounding effect of institutions
      - lends itself nicely to spatial analysis
empirical approach: data

1. introduction
2. geography & agriculture
3. geography & manufacturing
4. empirical approach
   - data
   - OLS
   - spatial dependence
   - spatial error
5. linking transition date to income
   - background
   - model and results
6. conclusion & discussion

- agriculture geography
  - Cultivation suitability index
    (Ramankutty et al., 2002)
  - Frost
    (Masters and McMillan, 2001)

- manufacturing geography
  - access to navigable waterways
    - oceans, seas, rivers
  - terrain
    - elevation, roughness

- date of transition from agriculture to manufacturing
  - Historic urban populations
    (Klein Goldewijk, 2005)

Cultivation suitability index:
- 0.000000 - 0.130000
- 0.130001 - 0.338549
- 0.338550 - 0.548463
- 0.548464 - 0.780000
- 0.780001 - 1.000000
1. Define transition to occur at this level of urbanization.

2. Observe the growth of urban populations conditional on geography.

3. Measure the difference in time it takes for two locations to reach the same transition point.

**empirical approach: data**

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empirical approach: regression

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• dependent variable
  – number of years that have elapsed since transition
    • $y = 2000$–transition year
  – transition defined according to varying thresholds
    • density of inhabitation
      – 1 person/sq. km.
      – 5.67 people/sq. km.
      (Acemoglu et al., 2002)
    • urban fraction of population
      – 10% urban
      – 25% urban
      – 50% urban

• independent variables
  – cultivation suitability index
    • ranges from 0 to 1
  – distance to navigable waterways
    • continuous distance to coastlines in km
    • navigable river, dummy based on Strahler Index ≥ 4
  – interactions between cultivation suitability and navigable waterways
  – frost days per year & frost squared
  – elevation in meters, standard deviation of elevation
  – country fixed effects
results: least squares

• Significant and strong effects attributable to geography

  – Rise in cultivation suitability from 0 to 1 introduces transition nearly 47 years earlier than average.

• Geography explains less of the time variation between locations as the threshold for transition rises

• Geography matters initially, direct effects on urbanization fade over time.

<table>
<thead>
<tr>
<th>Dependent variable is years ago since transition</th>
<th>Model 3 (10% urban)</th>
<th>Model 4 (25% urban)</th>
<th>Model 5 (50% urban)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>32.83*** (5.49)</td>
<td>14.10*** (3.11)</td>
<td>6.15*** (1.85)</td>
</tr>
<tr>
<td>Cultivation Suitability Index</td>
<td>46.82*** (1.56)</td>
<td>27.64*** (0.88)</td>
<td>13.35*** (0.53)</td>
</tr>
<tr>
<td>Log Coastal Distance</td>
<td>-2.03*** (0.15)</td>
<td>-1.42*** (0.08)</td>
<td>-0.98*** (0.05)</td>
</tr>
<tr>
<td>Navigable River</td>
<td>23.68*** (2.82)</td>
<td>13.81*** (1.60)</td>
<td>7.76*** (0.95)</td>
</tr>
<tr>
<td>Inverse Coastal Distance·Suitability Index</td>
<td>5.06*** (1.44)</td>
<td>3.02*** (0.81)</td>
<td>2.07*** (0.49)</td>
</tr>
<tr>
<td>Navigable River · Suitability Index</td>
<td>23.53*** (5.88)</td>
<td>2.07 (3.32)</td>
<td>1.25 (1.99)</td>
</tr>
<tr>
<td>Navigable River · Coastal Dummy</td>
<td>12.63*** (6.17)</td>
<td>11.70*** (3.49)</td>
<td>3.05 (2.09)</td>
</tr>
<tr>
<td>Frost</td>
<td>-0.113*** (0.023)</td>
<td>-0.087*** (0.013)</td>
<td>-0.051*** (0.008)</td>
</tr>
<tr>
<td>Frost²</td>
<td>-0.00002 (0.00006)</td>
<td>0.00003 (0.00004)</td>
<td>0.00004* (0.00002)</td>
</tr>
<tr>
<td>Elevation</td>
<td>-0.0009 (0.0007)</td>
<td>0.0009** (0.0004)</td>
<td>0.001*** (0.0002)</td>
</tr>
<tr>
<td>Standard Deviation of Elevation</td>
<td>0.022** (0.009)</td>
<td>0.009* (0.005)</td>
<td>0.001 (0.003)</td>
</tr>
<tr>
<td>Country</td>
<td>See Appendix</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.2173</td>
<td>0.2191</td>
<td>0.1656</td>
</tr>
<tr>
<td>Number of observations</td>
<td>61,929</td>
<td>61,929</td>
<td>61,929</td>
</tr>
</tbody>
</table>
testing and accounting for spatial spillovers

- Spatial dependence in transition timing implies possible spillovers.
  - Moran’s I is 0.22
- Spatial correlation in errors leads to biased estimates under ordinary least squares
- Spatial error model accounts for this correlation, provides unbiased estimates.

\[ Y = \beta X + \mu \]
\[ \mu = \lambda W \mu + \epsilon \]

- W is a weights matrix composed of neighboring observations’ values
### Results: Spatial Error

- **Significant spatial dependence in transition’s timing**
  - Spatial range extends across 50 neighbors grid cells.
  - Unobservable spatial process captured in the error term.
  - Pattern of geographic effects remains similar.
- **Spillovers are present**
  - but are not best captured by the transition date of a grid cell’s neighbors.
  - Some other unobserved effect is operating

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<tr>
<td>Cultivation Suitability Index</td>
<td>40.20*** (1.93)</td>
<td>10.46 (0.66)</td>
</tr>
<tr>
<td>Log Coastal Distance</td>
<td>-2.00*** (0.16)</td>
<td>-0.93 (0.053)</td>
</tr>
<tr>
<td>Navigable River</td>
<td>23.83*** (2.85)</td>
<td>7.90 (0.95)</td>
</tr>
<tr>
<td>Inverse Coastal Distance·Suitability Index</td>
<td>4.93*** (1.43)</td>
<td>2.10 (0.48)</td>
</tr>
<tr>
<td>Navigable River · Suitability Index</td>
<td>25.43*** (5.91)</td>
<td>2.13 (1.98)</td>
</tr>
<tr>
<td>Navigable River · Coastal Dummy</td>
<td>15.03** (6.17)</td>
<td>4.86 (2.07)</td>
</tr>
<tr>
<td>Frost</td>
<td>0.04 (0.03)</td>
<td>0.013 (0.011)</td>
</tr>
<tr>
<td>Frost²</td>
<td>-0.0004*** (0.00009)</td>
<td>-0.00014 (0.000034)</td>
</tr>
<tr>
<td>Elevation</td>
<td>-0.004*** (0.0008)</td>
<td>-0.001 (0.0003)</td>
</tr>
<tr>
<td>Standard Deviation of Elevation</td>
<td>0.015 (0.0096)</td>
<td>0.006 (0.003)</td>
</tr>
<tr>
<td>λ</td>
<td>0.68*** (0.017)</td>
<td>0.773*** (0.013)</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.06</td>
<td>0.07</td>
</tr>
</tbody>
</table>

Number of observations: 61,929
linking transition to income

- Does transition date matter to outcomes today?
- previous literature
  - Olsson and Hibbs (2005)
    - Test Diamond’s (1997) hypothesis that geography explains economic transition from hunter gatherer activity to sedentary agriculture
      - 6 regional variations in transition dates
      - climate, latitude, east-west axis, landmass, plants, and animals.
    - Biogeographic variables explain 40-50% of variation in log 1997 income
  - Putterman (2008) introduces country-specific transitions and population migration weights, find similar results
- In this paper, we follow the same pattern.
  - Test income as a function of transition date.
  - Aggregate grid cell values to the country-level.
linking transition to income

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[Graph showing the relationship between years since transition began and log income in 2000]
The earlier—and the faster—a location transitions, the larger the effect on modern income.

Introducing transition one year earlier raises income by up to 6%.

Control for country size (km.\(^2\)) accounts for large, empty countries.

Timing matters to income today.

### Results

<table>
<thead>
<tr>
<th>natural log of income in 2000</th>
<th>Model 1 (10% urban)</th>
<th>Model 2 (25% urban)</th>
<th>Model 3 (50% urban)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>7.30***</td>
<td>7.43***</td>
<td>7.89***</td>
</tr>
<tr>
<td></td>
<td>(0.13)</td>
<td>(0.11)</td>
<td>(0.093)</td>
</tr>
<tr>
<td>No. of years elapsed since transition</td>
<td>0.018***</td>
<td>0.030***</td>
<td>0.063***</td>
</tr>
<tr>
<td></td>
<td>(0.002)</td>
<td>(0.003)</td>
<td>(0.006)</td>
</tr>
<tr>
<td>No. of years elapsed since transition squared</td>
<td>-2.4e-5***</td>
<td>-7.3e-5***</td>
<td>-3.2e-4***</td>
</tr>
<tr>
<td></td>
<td>(5.01e-6)</td>
<td>(1.31e-5)</td>
<td>4.9e-5</td>
</tr>
<tr>
<td>Country Size (thousands of sq. km.)</td>
<td>0.164***</td>
<td>0.145***</td>
<td>0.116***</td>
</tr>
<tr>
<td></td>
<td>(0.036)</td>
<td>(0.034)</td>
<td>(0.033)</td>
</tr>
<tr>
<td>(R^2)</td>
<td>0.43</td>
<td>0.50</td>
<td>0.51</td>
</tr>
<tr>
<td>Number of Observations</td>
<td>166</td>
<td>166</td>
<td>166</td>
</tr>
</tbody>
</table>
discussion and conclusion

• A handful of economically-relevant geography variables can explain large differences in an area’s transition date.
  – Measurements are independent of institutional effects.
  – Institutions, as well as other country-level effects, are captured in country fixed effects.
• Spatial spillovers across grid cells are strong,
  – but the variable that captures this spillover remains unobserved.
• Transition’s timing can explain modern income.
  – A country’s historic transition date accounts for up to 51% of variation in year 2000 income.
• Areas for improvement
• Questions and comments